

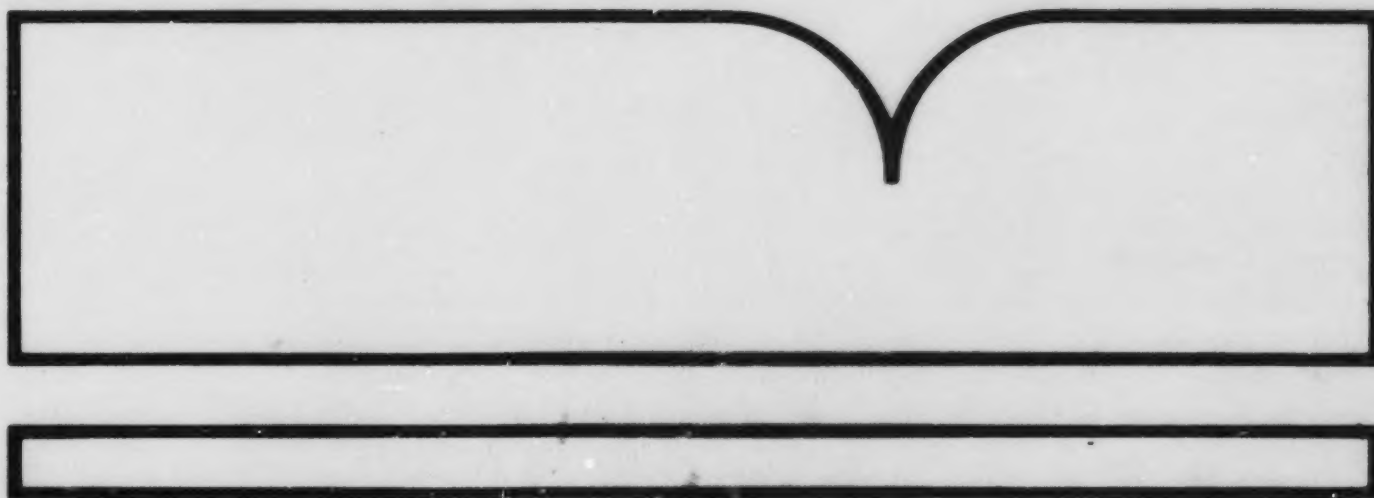
Evaluation of Subsurface
Conditions at Refinery Land
Treatment Sites

Texas A and M Univ., College Station

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16. ABSTRACT Soil cores were collected at 5 different sites that had been used for land treating refinery oily waste. Core samples were also collected from similar but untreated areas adjacent to the treated ones. Samples were analyzed for various constituents in an attempt to evaluate potential movement of the waste from the sites. Data indicates that metals from the waste applied to these sites typically remained in the treatment zone. Chromium did move to depths below the zone of incorporation in one site with acidic soil. At most sites low concentrations of hydrocarbons were found below the zone of incorporation. The potential for downward migration is typically greatest in coarse-textured, sandy soils, and less in fine-textured soils. Textural discontinuities appeared to help slow the downward movement of hydrocarbons.		
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AN EVALUATION OF SUBSURFACE CONDITIONS AT REFINERY
LAND TREATMENT SITES

by

K. W. Brown and L. E. Deuel, Jr.
Texas A&M University
College Station, Texas 77843

Submitted to the
American Petroleum Institute

Grant No. CR 807868

Project Officer

Carlton C. Wiles
Solid and Hazardous Waste Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in the problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

Land treatment of wastes has the potential of being an economically safe means of disposal of certain industrial waste streams. It is, however, still in its infancy and although some land treatment is being done, only limited information exists on the degradation and movement of waste constituents in soils. This study was conducted to partially fill this void.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

ABSTRACT

Soil cores were collected from five land treatment facilities being used for the disposal of various solid wastes from oil refineries. Cores from similar but untreated soils adjacent to each facility were collected for comparison. The samples were analyzed for chemical constituents to determine whether there was any evidence of the movement of waste constituents in the soil.

The sites selected represented diverse climatic regions, and the soils ranged in texture from clay to sand. The facilities had been in operation from 1 to 7 years before sampling and had received a wide range of waste applications.

Data from this study indicate that metals from the waste applied typically remain in the treatment zone and concentrations generally are within ranges considered normal for soils. Only at one site which had acidic soil did chromium move to depths below the zone of incorporation. The potential exists for possible downward migration of land treated hydrocarbons. At most sites, only very low concentrations of hydrocarbons were found at limited depths below the zone of incorporation. Since these materials remain in the aerobic zone, they will likely degrade with time. At one site with sandy soils, hydrocarbons were detected to 224cm (88.2 in.) in depth at which degradation would be expected to occur only very slowly, but this occurrence was determined to be the result of previous industrial contamination.* The potential for downward migration is typically greatest in coarse-textured, sandy soils, and less in fine-textured soils. Textural discontinuities appear to help slow the downward movement of hydrocarbons. The results indicate that with proper site selection and application rates, the potential for groundwater contamination from land treatment of refinery waste is minimal.

This report was submitted in fulfillment of Cooperative Agreement No. CR 807868-01 by Texas A&M Research Foundation under the sponsorship of the U.S. Environmental Protection Agency and the American Petroleum Institute. This report covers the period

* The site reported that core samples taken before applying waste to the landtreatment area showed oil levels similar to those found in this study.

November 5, 1980 to November 4, 1981 and work was completed
as of April 1, 1982.

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SECTION 1

INTRODUCTION

Land treatment has been demonstrated to be an effective method of disposing of waste streams that contain biodegradable organic materials. The various constituents of the land-treated waste that do not degrade accumulate in the soil; however, some of these constituents could migrate down through the profile if the retention capacity is exceeded.

Raymond et al. (1975) showed that oil applied to soils at the rate of 100 barrels (bbl)/acre resulted in no oil lost, either in runoff or leachates generated. They reported significant ether-extractable materials in leachates, which suggests an incomplete degradation and mobility of some components of the oil.

Water quality could be adversely affected by the low redox potentials associated with saturated soil conditions or by overloading with high BOD materials if contaminant solubilities are significantly enhanced. Fuller (1977) reported enhanced mobilities for As, Cr, Fe, and Zn under reducing environments (unoxxygenated). Movement of metals through soluble metal-organic complexes were also reported as a potential means of enhanced mobility.

Applications of organics to soil tend to increase soil acidity (Britton et al., 1976). Most metals have increased solubilities under acidic soil conditions (Chaney, 1973; MacLeon and Dekker, 1976). The potential for enhanced mobility largely depends on the initial soil reaction and the buffer capacity of the soil if it is not amended with liming agents. Specific information concerning the fate of various organic constituents in land treatment operations also is limited.

Anions present special problems with respect to their rate of movement through soils relative to water (Thomas and

Swoboda, 1970). The phenomenon apparently depends on the cation exchange capacity so that negatively charged surfaces repel anions, effectively reducing the volume of water needed to leach a given anion.

The primary objective of this study was to determine the potential for downward migration of constituents following the long-term use of specific sites for land treatment of refinery waste sludges.

SECTION 2

EXPERIMENTAL DESIGN

A sampling program was initiated to evaluate the presence of waste constituents in the surface and subsurface soil. Samples were collected both from soils that had been treated with refinery wastes and from adjacent soils that had not been used for waste disposal (referred to as untreated soil). Samples were collected from similar depths at both locations, and the results of the analyses were compared to determine whether waste constituents had moved. Groundwater and soil pore water analyses were not conducted.

With the assistance of the API task force, five sites were selected that had been used for land treatment of oily wastes for several years. Sites were selected principally on the basis of geographical and climatological diversity. Detailed climatological data for each site (Appendix A) were calculated based on the 30-year mean for the nearest weather station. In view of the broad range of characteristics of the five sites (i.e. wastes handled, application rates, soil types, application method), it is believed that this effort adequately reflects current refinery operations (Table 1).

Sampling

The sampling scheme was modified as necessary to meet field conditions. Each treatment site was surveyed and 4 to 5 locations were selected as representative areas. Cores were taken from each spot and composited with depth. About 12 depth intervals were selected at each site depending on the soil profile. Descriptions of the treatment sites and the positions from which samples were taken are given in Appendix B. At each land treatment site, one soil core was taken from an untreated soil adjacent to the treated area. Detailed descriptions of the soils native to each land treatment facility is given in Appendix B. Samples were placed in glass containers and transported to the laboratory, where they were maintained in cold storage until analyzed.

Table 1. History of Waste Application at Sampling Sites.

Description	A	B	C	D	E
Type of Waste Applied:					
API Separator Sludge	✓	✓	✓	✓	✓
DAF Sludge	✓	✓	✓	✓	✓
Tank Bottom Sediment		✓	✓	✓	✓
Filter Clays			✓	✓	
ETP Sludge		✓	✓	✓	
Slop Oil Emulsion		✓	✓	✓	
Treatment Pond Sludge	✓				
Leaded Sludge					✓
Rate of Application	1-4% oil	277 bbl acre/yr	3020 bbl/acre/ month	680 bbl/A/ month	80 yd ³ /A/yr
Method of Application	Applied to surface and disced several times; tilled twice.	Applied to surface and disced.	Subsurface injection and tilled repeatedly.	Applied to surface and tilled twice.	Applied to surface and tilled.
Date That Landtreatment Begun	May 1973	Late 1974	October 1979	June 1976	March 1979
Last Application Date Before Sampling	July 1979	August 1980	December 3, 1980	October 9, 1980	Prior to Nov. 19, 1980
Date of Sampling	Nov. 24, 1980	July 1-2, 1981	Dec. 8-11, 1980	January 7, 1981	March 16-20, 1981
Time Since Last Application	15 months	11 months	1 week	3 months	Over 4 months

* Effluent treatment plant.

Site History

Since the history of past applications will have a large bearing on interpretation of analytical data, a concerted effort was made to obtain a consistent and detailed history of each site. This information included beginning dates, application rates and methods, types of wastes applied, and the date of the last application before sampling. A summary of this information is presented in Table 1.

Analyses

A schematic diagram of the analyses performed on each soil sample is given in Figure 1. Details of the analytical procedures are presented below.

Soil Properties: Appropriate soil analyses were made to verify field descriptions and provide a data base for correlative interpretation of the results. Parameters included pH (Peech, 1965), specific conductance (Bower and Wilcox, 1965), texture (Day, 1965), cation exchange capacity (Chapman, 1965a), and soluble and exchangeable cationic distribution (Chapman, 1965b). In addition to the above soil properties, soils were analyzed for $\text{NO}_3\text{-N}$ (Bremner, 1965) and chloride and sulfate by specific anion electrode technique.

Metals: Subsamples of each composite were digested with nitric acid and hydrogen peroxide. The latter was added to facilitate the destruction of organics and oxidation of the various metallic species. Following digestion, metals were analyzed according to EPA protocol (EPA, 1979, Methods 206.3, 213.1, 218.1, 245.1, 239.1, 270.2, 249.1, and 286.1). Atomic absorption spectroscopic technique was used for specific metal analyses, except for arsenic, which was analyzed by colorimetric technique following conversion to its hydride and complexing with silver diethyldithiocarbamate in a pyridine base. An aliquot of the metal digest was evaporated to a very low volume in the presence of a sulfuric, hydrochloric acid matrix to purge traces of nitric from the sample before arsine generation.

Analytical procedures have been statistically evaluated for the metals of interest using NBS reference soils.

Organics: In addition to the above inorganic soil properties and/or constituents, each segmented core was analyzed specifically for total organic carbon (Allison,

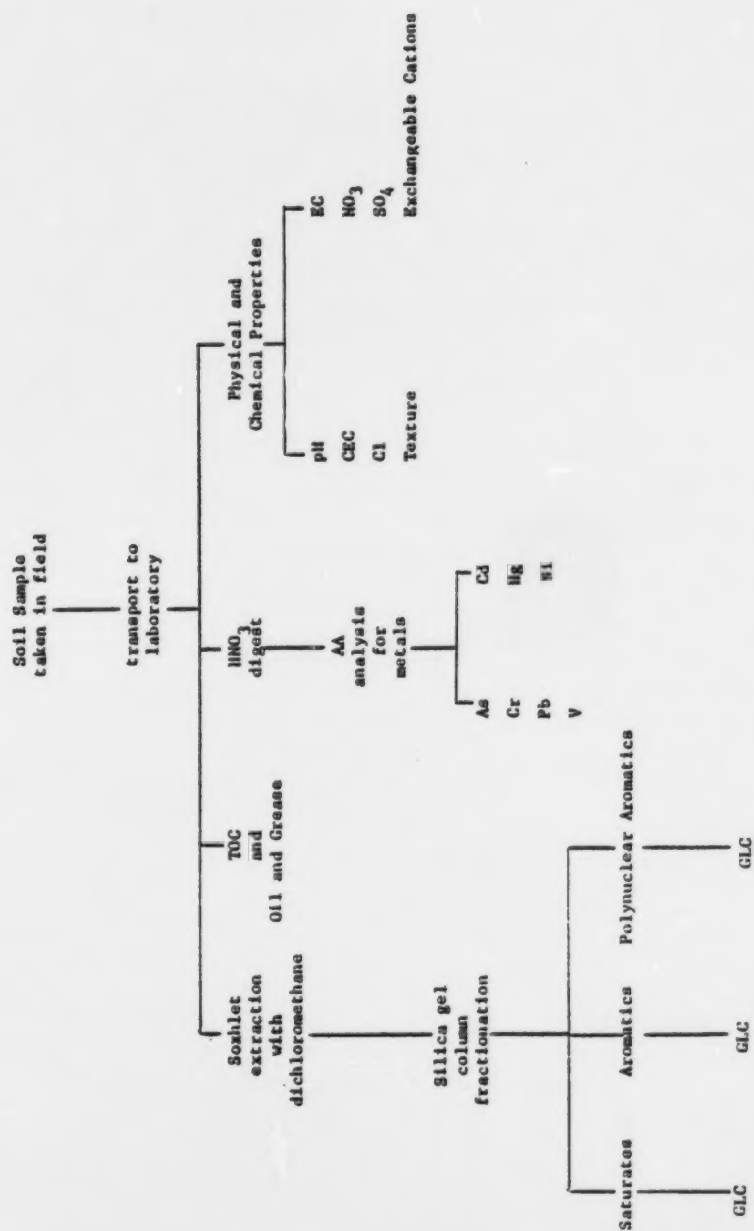


Figure 1. Schematic diagram of the analytical system.

1965) and extractable oil and grease by a modified procedure of Dibble and Bartha (1979).

Organics were Soxhlet extracted from all soil samples maintained at field moisture content. Between 10 to 20 g of soil on a dry weight basis was weighed in an extraction thimble and Soxhlet extracted with 75 to 250 ml of CH_2Cl_2 for four hours. Greater amounts of solvent were used for the samples which visually appeared to have greater amounts of oily residue. The extract was dried by passing it through a bed of 15 g anhydrous Na_2SO_4 . The extract was then flash evaporated to less than 50² ml⁴ and brought up to 50 ml volume by addition of CH_2Cl_2 . One 5 ml aliquot was evaporated and gravimetrically analyzed for residue. A 5 ml aliquot of the extract from soil samples from the upper 3 depth intervals from each location was fractionated before GLC analysis.

Fractionation into saturates, aromatics and higher condensed polynuclear aromatics was achieved by the method suggested by Warner (1976). A five ml aliquot was evaporated with a gentle stream of dry nitrogen and resolubilized in hexane for loading onto 10 g activated silica gel in a column. The sample vial was rinsed with approximately 2 ml petroleum ether which was also transferred to the column. Saturates were eluted with 25 ml petroleum ether. The sample vial was then rinsed with 2 ml 20% methylene chloride in petroleum ether which was transferred to load the column. Aromatics were then eluted with 50 ml of 20% methylene chloride in petroleum ether. A final rinse of the sample vial was made with 5 ml methylene chloride which was transferred to the column, and followed by elution of carbazoles and some higher condensed polynuclear aromatics with 20 ml of methylene chloride. The silica gel was finally rinsed with 50 ml methanol to elute some of the higher molecular weight materials. This extract was analyzed by High Performance Liquid Chromatography (HPLC) as described below.

Soil samples from all lower depths were similarly extracted with CH_2Cl_2 and small aliquots went directly to GLC analysis without fractionation. Each of the three extracts were analyzed by GLC using a temperature programmed Tracor Model 560 GC, equipped with a flame ionization detector. The GLC was fitted with a 0.64 cm i.d. by 1.8 m long glass column packed with 3% OV-1 on 80/100 mesh chromosorb w. Injector temperature was maintained at 235°C. The column oven was programmed between 100 and 240°C at a rate of 3°C/min with an initial 10 min hold and a final 40 min hold.

High Performance Liquid Chromatography (HPLC)

An aliquot of the methanol extract (Fraction 5) from surface horizon and an aliquot of the total extract from samples collected deeper in the profile were systematically analyzed by HPLC for phenol and phenolic derivatives according to the procedure detailed in L. C. Varian Report No. 96. A Beckman Model 421 liquid chromatographic unit equipped with a Beckman ultrasphere ODS reverse phase column in conjunction with a variable UV detector system was used to separate and analyze for phenols. The mobile phase was water/acetonitrile/1% acetic acid. A gradient of 30% to 80% acetonitrile/1% acetic acid in 20 min at a flow rate of 1.0 ml/min was used, followed by a 6-min isocratic run at 80% acetonitrile/1% acetic acid. The regeneration step entailed a 10-min gradient from 80% to 30% acetonitrile/1% acetic acid and followed by a 20-min equilibration with 30% acetonitrile/1% acetic acid at 1 ml/min.

Phenols were routinely monitored at 280 nm. Samples showing suspect peaks by comparison with standard retention times were reinjected and monitored at 254 nm. The ratio of the suspect peak intensity of 280 nm to the intensity at 254 nm was compared with the ratio for the appropriate standard compound. If the 280/254 ratio for a suspect peak varied significantly from the known ratio, it was rejected as a possible phenol peak.

SECTION 3

RESULTS AND DISCUSSION

Particle Size Distribution

Physical properties of a soil are defined as those characteristics, processes, or reactions of a soil which are caused by physical forces but, for all practical purposes, are integrally related to particle size. The particle size distribution determined for treated soils and untreated soils with respect to depth are shown in Tables 2 through 6, along with the corresponding USDA textural classification. Site A reflects a medium textured (loam) surface over a clay. Treated and untreated soils at Site B ranged from medium to coarse texture throughout the profiles. A coarse texture (sand) dominated the profile developed at Site C. Site D was typically medium textured, becoming coarser with depth. The soils at Site E are clay throughout the profile.

The mobility of most constituents would be favored by open coarse textured soils such as found at Site C. Anionic mobilities may be enhanced in deep clay profiles. Textural discontinuities, such as those which occur at Site A, B, and D (Tables 2, 3, and 5) would tend to impede water transmission and downward movement of soluble constituents within the profile. The greater macroporosity of coarse textured soils tend to favor natural aeration necessary for the microbial oxidation of organics. Textural discontinuities in high rainfall areas may prove detrimental to degradation rates of organics through lowered gaseous exchange rates.

Cationic Distribution

The cation exchange capacity (CEC) is the total amount of exchangeable cations that a soil can adsorb. Among the cations normally held by the CEC are NA, Ca, Mg, and K. Soils having high clay content and organic matter (OM) content usually have a high CEC. A moderate to high CEC

Table 2. USDA Texture and Particle Size Distribution of the Untreated and Treated Soils at Site A.

Site	Depth (cm)	Depth (in)	USDA Texture †	Particle Size (%)		
				Sand	Silt	Clay
A- Untreated Soil	0-15	0-6	SCL	48	23	29
	15-23	6-9	L-CL	44	29	27
	23-30	9-12	C	31	27	42
	30-53	12-21	C	24	27	49
	53-76	21-30	C	30	23	47
	76-102	30-40	SCL	46	27	27
	102-127	40-50	C	22	25	53
	127-152	50-60	CL	36	29	35
A-Treated Soil	0-15	0-6	SIL	30	51	19
	15-23	6-9	C	44	9	47
	23-30	9-12	C	42	4	54
	30-53	12-21	C	43	13	44
	53-76	21-30	C-CL	38	22	40
	76-102	30-40	C	40	17	43
	102-127	40-50	C	43	15	42
	127-152	50-60	C	41	8	51

† SCL - sandy clay loam
L - loam
CL - clay loam
C - clay
SIL - silt loam
SL - sandy loam
S - sand
LS - loamy sand

Table 3. USDA Texture and Particle Size Distribution of the Untreated and Treated Soils at Site B.

Site	Depth (cm)	Depth (in)	USDA Texture [†]	Particle Size (%)		
				Sand	Silt	Clay
B-Untreated Soil	0-15	0-6	L	42	35	23
	15-30	6-12	SL	72	17	11
	30-46	12-18	SL	76	14	10
	46-61	18-24	S	93	3	4
	61-76	24-30	S	91	2	7
	76-91	30-36	S	94	2	4
	91-122	36-48	LS	82	10	8
	122-152	48-60	L	41	37	22
	152-183	60-72	L	48	31	21
	183-244	72-96	SL	66	21	13
	244-305	96-120	SL	54	44	2
	305-366	120-144	SL	55	43	2
B-Treated Soil	0-15	0-6	SL	53	30	17
	15-30	6-12	SL	54	30	16
	30-46	12-18	L	46	36	18
	46-61	18-24	L	43	41	16
	61-76	24-30	LS-SL	76	18	6
	76-91	30-36	SL	75	19	6
	91-122	36-48	SL	65	19	16
	122-152	48-60	SL	65	17	18
	152-183	60-72	SL	70	16	14
	183-244	72-96	SL-SCL	62	18	20
	244-305	96-120	SCL	47	27	26
	305-366	120-144	SCL	48	26	26

Table 4. USDA Texture and Particle Size Distribution of the Untreated and Treated Soils at Site C.

Site	Depth (cm)	Depth (in)	USDA Texture	Particle Size (%)		
				Sand	Silt	Clay
C- Untreated Soil	0-15	0-6	SL	81	6	13
	15-30	6-12	LS	96	8	6
	30-46	12-18	S-LS	88	6	6
	46-61	18-24	LS	88	3	9
	61-76	24-30	SL	80	6	14
	76-91	30-36	SL	74	11	15
	91-122	36-48	SL	81	4	15
	122-152	48-60	SL	83	2	15
	152-183	60-72	SL	83	2	15
	183-244	72-96	SL	80	2	18
	244-305	96-120	LS	85	2	13
	305-366	120-144	S	93	5	2
C-Treated Soil	0-15	0-6	SL	73	17	10
	15-30	6-12	LS	84	5	11
	30-46	12-18	SL	77	9	14
	46-61	18-24	LS	87	4	9
	61-76	24-30	S	92	3	5
	76-91	30-36	LS	85	3	12
	91-122	36-48	LS	87	4	9
	122-152	48-60	LS-SL	82	6	12
	152-183	60-72	LS	85	5	10
	183-244	72-96	LS	85	4	11
	244-305	96-120	LS	85	5	10
	305-366	120-144	S	90	1	9

Table 5. USDA Texture and Particle Size Distribution of the Untreated and Treated Soils at Site D.

Site	Depth (cm)	Depth (in)	USDA Texture	Particle Size (%)		
				Sand	Silt	Clay
D-Untreated	0-10	0-4	SL	75	15	10
	10-20	4-8	SL	77	12	11
	20-30	8-12	SCL-SC	56	9	35
	30-46	12-18	SC	47	6	47
	46-61	18-24	SC	48	12	40
	61-76	24-30	SC	54	10	36
	76-91	30-36	SCL	53	15	32
	91-122	36-48	SC	51	12	37
	122-152	48-60	SCL	65	9	26
	152-183	60-72	SCL	68	10	22
	183-244	72-96	SCL	63	12	25
	244-305	96-120	SCL	67	12	21
	305-366	120-144	S	91	1	8
D-Treated Soil	0-10	0-4	SCL	64	13	23
	10-20	4-8	SCL	60	11	29
	20-30	8-12	SCL	58	9	33
	30-46	12-18	SCL	60	8	32
	46-61	18-24	SCL	53	15	32
	61-76	24-30	SCL	57	12	31
	76-91	30-36	SCL	53	18	29
	91-122	36-48	SCL	51	19	30
	122-152	48-60	SCL	52	17	31
	152-183	60-72	SCL	54	18	28
	183-244	72-96	SL	70	11	19
	244-305	96-120	LS	86	5	9
	305-366	120-144	S	90	4	6

Table 6. USDA Texture and Particle Size Distribution of the Untreated and Treated Soils at Site E.

Site	Depth (cm)	Depth (in)	USDA Texture	Particle Size (%)		
				Sand	Silt	Clay
E-Untreated Soil	0-30	0-12	C	25	29	46
	30-46	12-18	C	20	32	48
	46-61	18-24	C	28	22	50
	61-76	24-30	-	-	-	-
	76-91	30-36	C	17	23	60
	91-122	36-48	C	21	21	58
	122-152	48-60	C	14	11	75
	152-183	60-72	C	11	7	82
	183-244	72-96	C	11	22	67
	244-305	96-120	C	16	18	66
	305-366	120-144	C	16	11	73
E-Treated Soil	0-30	0-12	C	25	25	50
	30-46	12-18	C	16	31	53
	46-61	18-24	C	16	29	55
	61-76	24-30	C	15	24	61
	76-91	30-36	C	18	21	61
	91-122	36-48	C	16	21	63
	122-152	48-60	C	18	18	64
	152-183	60-72	C	13	25	62
	183-244	72-96	C	15	24	61
	244-305	96-120	C	13	29	58
	305-366	120-144	C	16	26	58

would be advantageous to a land treatment site as the CEC would help prevent migration of added waste constituents.

Profiles reflecting the CEC and cationic distribution are shown in Tables 7 through 11. Some of the calcium and magnesium reported as exchangeable cations exceed CEC values due to sparingly soluble sulfate and/or carbonate salts. Cation exchange capacities generally reflect corresponding clay contents and are within the normal ranges for soils. Some of the treated sites are considerably higher in CEC possibly due to the organics applied. The high sodium saturations occur in both the treated and untreated soil profiles at Sites A and C. The data suggest that after the utilization of these sites in the land treatment of refinery waste there has only been a slight alteration of the cationic distribution towards sodium, except at Site A where the sodium levels were greater for the untreated soil.

Soil Reaction

Comparative soil reaction are presented in pH profiles for both untreated and treated soils at each site (Figures 2 through 6). Site A demonstrates the typical acidifying reaction normal to the degradation of organics in soil.

For the most part the influence of land treatment on soil reactions were attenuated within the upper 91 to 183 cm (3 to 6 ft) of the profiles sampled, attenuation being reflected by convergence of measured values.

The divergence of profiles shown for Sites B and C are attributed to the coarse texture and associated low buffer capacity, although it should be noted that values differ generally by less than one pH unit.

Soil reactions for both treated Sites D and E exceed values for the untreated sites to a depth of 1.5 m. Although initial waste properties are unknown, the pH profile suggests the increased alkalinity stems from the waste applications.

It is desirable to have a pH ranging between 6 and 8 in a land treatment facility since this is the most favorable range for soil microorganisms, concomitant to a functional facility. This pH range favors the solubility of essential nutrients and sorption of heavy metals.

Table 7. Cation Exchange Capacity, Exchangeable Cations and Percent Sodium Saturation in the Untreated and Treated Soils at Site A.

Site	Depth (cm)	Depth (in)	CEC (meq/100g)	Exchangeable Cations				Na Saturation (%)
				Na	K	Ca	Mg	
				(meq/100g)				
A-Untreated Soil	0-15	0-6	7.1	1.8	0.4	18.1	4.7	25.4
	15-23	6-9	7.2	5.2	0.2	45.0	12.2	72.2
	23-30	9-12	10.1	7.2	0.2	314.6	16.8	71.3
	30-53	12-21	15.1	8.9	0.2	39.5	9.2	58.9
	53-76	21-30	12.7	10.4	0.3	45.8	10.6	81.9
	76-102	30-40	9.2	10.4	0.3	35.8	8.0	53.1
	102-127	40-50	9.6	7.3	0.3	36.1	12.9	37.2
	127-152	50-60	9.6	7.1	0.3	54.9	5.9	36.2
A-Treated Soil	0-15	0-6	11.3	0.5	1.6	20.0	5.2	4.4
	15-23	6-9	12.9	2.5	0.6	33.8	7.7	19.3
	23-30	9-12	13.3	5.1	0.3	61.5	9.9	38.3
	30-53	12-21	14.5	4.8	0.3	46.7	9.6	33.1
	53-76	21-30	15.3	6.2	0.3	47.4	9.1	40.5
	76-102	30-40	17.4	7.3	0.4	51.0	7.9	42.0
	102-127	40-50	15.3	5.8	0.4	52.8	8.2	37.9
	127-152	50-60	12.1	6.1	0.3	55.4	14.3	50.4

Table 8. Cation Exchange Capacity, Exchangeable Cations and Percent Sodium Saturation in the Untreated and Treated Soils at Site B.

Site	Depth (cm)	Depth (in)	CEC (meq/100g)	Exchangeable Cations				Na Saturation (%)
				Na	K	Ca	Mg	
				(meq/100g)				
B-Untreated Soil	0-15	0-6	4.1	0.1	0.1	1.5	1.8	2.4
	15-30	6-12	2.4	0.1	0.0	1.5	0.1	4.2
	30-46	12-18	1.0	0.1	0.0	0.9	0.1	10.0
	46-61	18-24	1.0	0.1	0.0	0.7	0.1	10.2
	61-76	24-30	1.0	0.1	0.0	0.8	0.2	10.5
	76-91	30-36	0.7	0.1	0.0	0.6	0.2	15.4
	91-122	36-48	1.4	0.1	0.0	1.6	0.6	0.5
	122-152	48-60	5.4	0.1	0.1	6.4	3.7	1.9
	152-183	60-72	7.5	0.1	0.1	6.2	3.5	1.3
	183-244	72-96	4.4	0.1	0.1	3.6	1.7	2.3
	244-305	96-120	5.5	0.1	0.2	13.3	2.5	1.8
	305-366	120-144	4.0	0.1	0.2	23.0	2.3	2.5
B-Treated Soil	0-15	0-6	3.5	0.4	0.0	25.0	0.8	11.4
	15-30	6-12	4.5	0.1	0.3	3.8	1.8	2.2
	30-46	12-18	4.8	0.1	0.3	4.0	1.4	2.1
	46-61	18-24	3.7	0.1	0.2	3.6	1.3	2.7
	61-76	24-30	1.7	0.1	0.2	5.3	1.2	5.9
	76-91	30-36	2.3	0.1	0.1	2.3	0.7	4.3
	91-122	36-48	2.4	0.1	0.1	2.7	1.6	4.2
	122-152	48-60	4.5	0.1	0.1	5.2	3.5	2.2
	152-183	60-72	5.2	0.1	0.1	5.0	3.9	1.9
	183-244	72-96	4.6	0.1	0.1	4.3	3.0	2.2
	244-305	96-120	6.6	0.1	0.1	6.4	4.8	1.5
	305-366	120-144	6.0	0.1	0.1	6.5	4.5	1.7

Table 9. Cation Exchange Capacity, Exchangeable Cations and Percent Sodium Saturation in the Untreated and Treated Soils at Site C.

Site	Depth (cm)	Depth (in)	CEC (meq/100g)	Exchangeable Cations				Na Saturation (%)
				Na	K	Ca	Mg	
				(meq/100g)				
C-Untreated Soil	0-15	0-6	1.7	0.3	0.2	42.7	1.5	17.6
	15-30	6-12	2.6	0.2	0.3	5.9	1.9	7.7
	30-46	12-18	2.1	0.3	0.2	12.5	1.1	14.3
	46-61	18-24	2.2	0.3	0.1	2.9	1.2	13.6
	61-76	24-30	2.6	1.2	0.1	22.4	1.5	46.2
	76-91	30-36	2.0	0.9	0.1	1.9	1.3	45.0
	91-122	36-45	2.3	0.9	0.1	1.8	1.9	36.0
	122-152	48-60	3.6	0.4	0.0	2.8	2.8	11.1
	152-183	60-72	4.0	0.3	0.1	2.9	3.2	7.5
	183-244	72-96	4.8	0.3	0.1	2.6	3.8	6.3
	244-305	96-120	3.0	0.2	0.0	1.7	2.4	6.7
305-366	120-144	1.5	0.04	0.0	0.8	1.0	2.7	
C-Treated Soil	0-15	0-6	5.5	1.2	0.3	27.9	4.6	21.8
	15-30	6-12	3.2	0.4	0.1	15.1	1.5	12.5
	30-46	12-18	3.0	0.2	0.1	9.4	1.7	6.7
	46-61	18-24	2.5	0.3	0.1	2.0	1.6	12.0
	61-76	24-30	2.0	0.2	0.1	2.2	2.0	10.0
	76-91	30-36	2.3	0.2	0.1	2.3	1.8	8.7
	91-122	36-48	2.6	0.6	0.1	2.3	1.9	23.1
	122-152	48-60	2.9	0.4	0.1	2.4	2.0	13.8
	152-183	60-72	2.3	0.3	0.0	1.6	1.7	13.0
	183-244	72-96	2.8	0.4	0.0	1.3	1.7	14.3
	244-305	96-120	4.4	0.2	0.0	1.4	1.8	4.5
305-366	120-144	2.1	0.0	0.0	1.4	1.4	0.0	

Table 10. Cation Exchange Capacity, Exchangeable Cations and Percent Sodium Saturation in the Untreated and Treated Soils at Site D.

Site	Depth (cm)	Depth (in)	CEC (meq/100g)	Exchangeable Cations				Na Saturation (%)
				Na	K	Ca	Mg	
				(meq/100g)				
D-Untreated Soil	0-10	0-4	3.3	0.0	0.4	6.1	0.6	0.0
	10-20	4-8	3.1	0.1	0.2	4.3	0.6	3.2
	20-30	8-12	9.2	1.2	0.3	9.3	4.7	13.0
	30-46	12-18	12.6	3.8	0.2	10.3	6.8	29.7
	46-61	18-24	1.0	4.3	0.3	9.3	5.4	43.0
	61-76	24-30	9.1	3.8	0.3	18.4	4.7	42.0
	76-91	30-36	8.4	3.9	0.3	36.3	5.9	46.4
	91-122	36-48	9.6	3.5	0.3	31.5	3.9	36.5
	122-152	48-60	7.0	2.8	0.2	17.1	3.9	40.0
	152-183	60-72	5.7	2.1	0.2	28.2	3.3	36.8
	183-244	72-96	6.5	1.4	0.2	30.1	2.9	21.5
	244-305	96-120	5.5	1.2	0.2	34.0	2.8	21.8
305-366	120-144	2.1	0.4	0.2	25.5	0.8	19.0	
D-Treated Soil	0-10	0-4	8.7	1.1	0.0	19.0	3.2	12.6
	10-20	4-8	9.9	1.2	0.0	18.0	3.0	12.1
	20-30	8-12	7.9	1.2	0.0	9.3	3.1	15.2
	30-46	12-18	6.8	1.9	0.0	32.6	3.8	27.9
	46-61	18-24	6.3	1.2	0.0	30.3	4.0	19.0
	61-76	24-30	5.8	2.2	0.0	30.6	3.0	37.9
	76-91	30-36	7.5	1.5	0.0	36.0	3.0	20.0
	91-122	36-48	6.6	1.5	0.0	30.0	2.6	22.7
	122-152	46-60	6.5	2.8	0.0	32.8	3.0	43.0
	152-183	60-72	7.0	2.5	0.0	26.9	2.5	35.7
	183-244	72-96	4.4	1.3	0.0	30.4	3.2	29.5
	244-305	96-120	2.3	0.7	0.0	28.9	1.7	30.4
305-366	120-144	1.6	0.4	0.0	28.5	1.2	25.0	

Table 11. Cation Exchange Capacity, Exchangeable Cations and Percent Sodium Saturation in the Untreated and Treated Soils at Site E.

Site	Depth (cm)	Depth (in)	CEC (meq/100g)	Exchangeable Cations				Na Saturation (%)
				Na	K	Ca	Mg	
				(meq/100g)				
E-Untreated Soil	0-30	0-12	16.1	0.1	0.0	21.0	5.7	0.6
	30-46	12-18	13.4	0.4	0.0	16.7	6.9	3.0
	46-61	18-24	15.9	0.8	0.0	17.1	9.7	5.0
	61-76	24-30	17.4	0.9	0.0	17.4	10.2	5.2
	76-91	30-36	18.0	1.0	0.0	17.9	11.3	5.6
	91-122	36-48	18.4	1.3	0.0	19.3	12.8	7.0
	122-152	48-60	14.4	1.0	0.0	17.2	12.6	6.9
	152-183	60-72	15.8	0.7	0.0	24.9	13.6	4.4
	183-244	72-96	13.4	1.9	0.2	12.3	11.1	14.2
	244-305	96-120	12.0	2.5	0.3	31.4	14.7	20.8
	305-366	120-144	10.7	2.0	0.3	13.4	10.5	18.7
E-Treated Soil	0-30	0-12	11.4	0.8	0.0	33.5	7.4	7.0
	30-46	12-18	17.6	1.1	0.0	17.2	9.6	6.3
	46-61	18-24	23.2	0.3	0.0	18.5	10.8	1.2
	61-76	24-30	23.8	0.6	0.0	26.5	10.7	2.5
	76-91	30-36	18.1	1.4	0.0	32.6	12.1	7.7
	91-122	36-48	20.5	1.3	0.0	38.3	12.5	6.3
	122-152	48-60	22.1	1.6	0.0	20.4	12.4	7.2
	152-183	60-72	12.9	2.3	0.0	28.0	13.3	17.8
	183-244	72-96	11.9	2.4	0.0	37.2	12.7	20.2
	244-305	96-120	10.6	2.3	0.0	37.2	11.7	21.7
	305-366	120-144	9.6	1.7	0.0	37.4	9.5	17.7

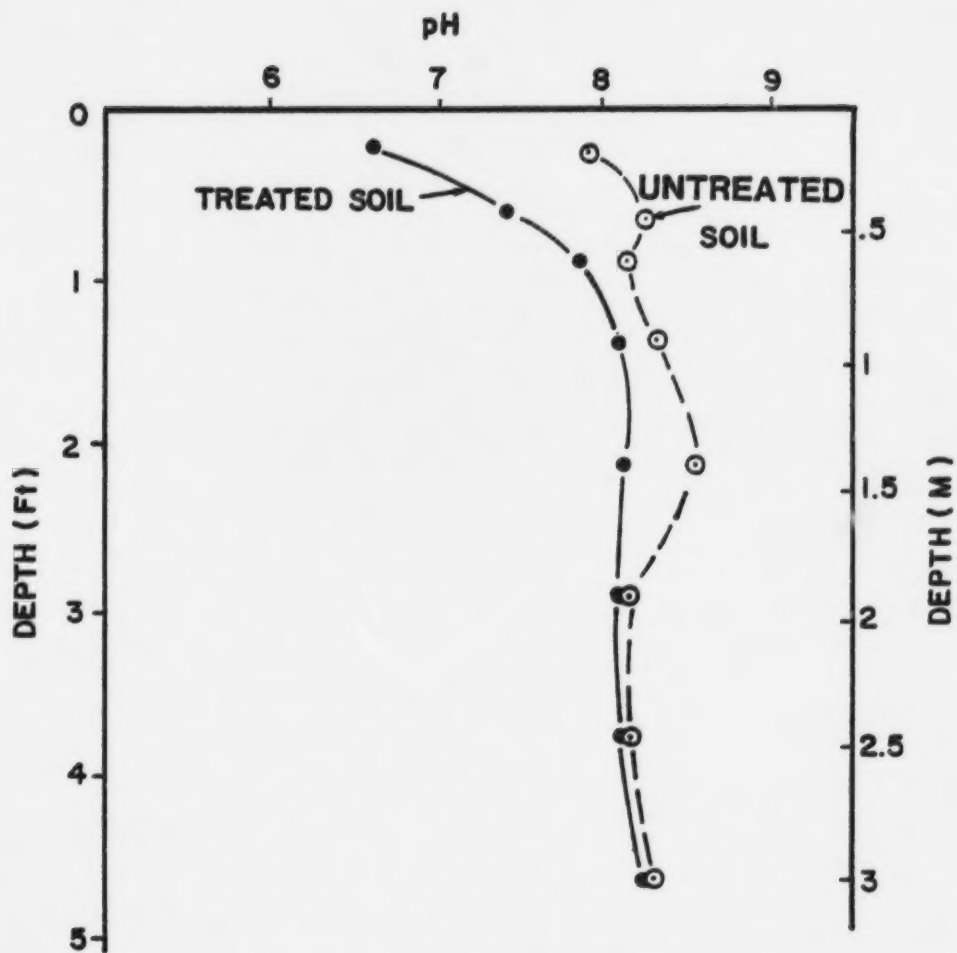


Figure 2. pH profile at Site A.

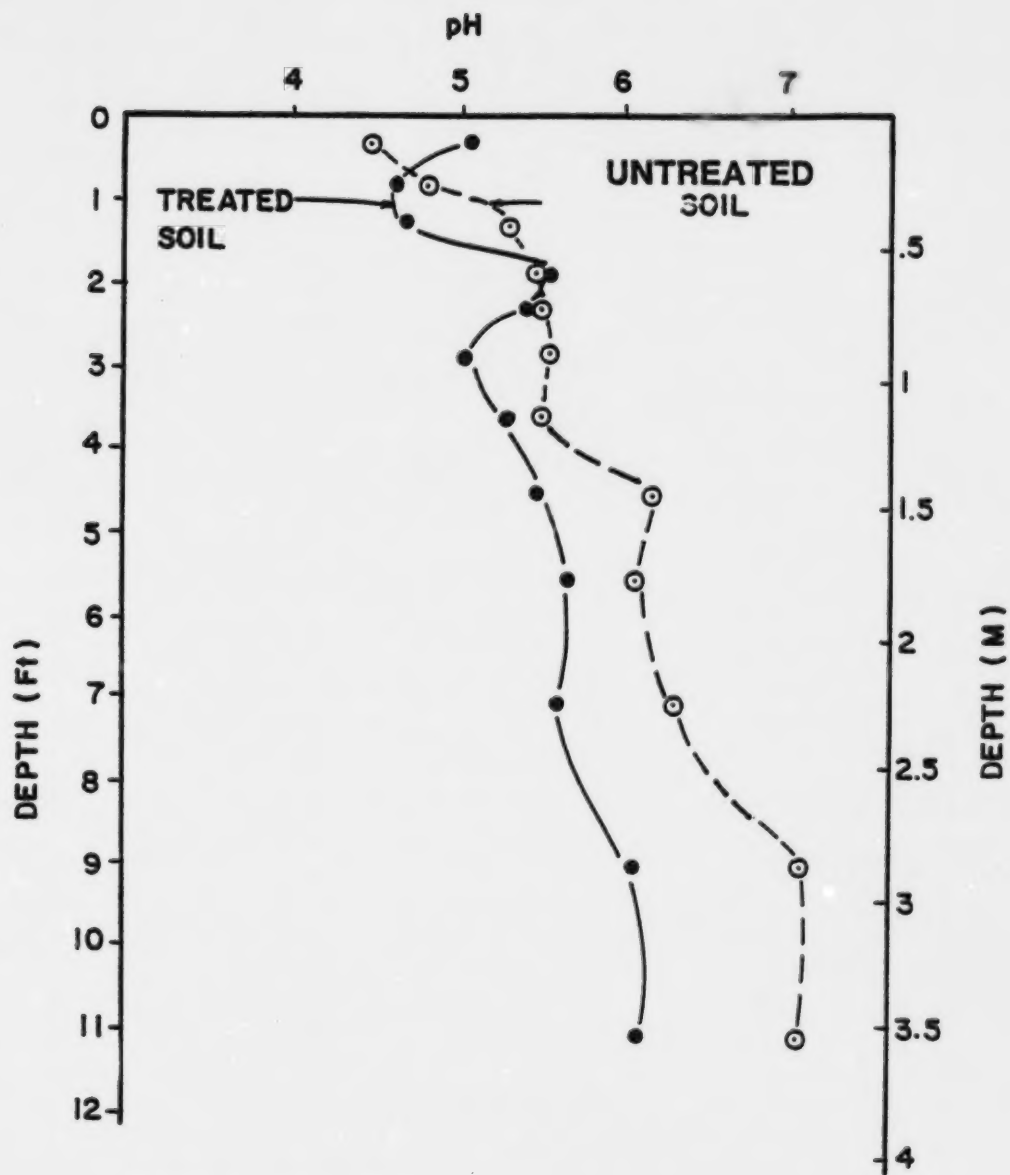


Figure 3. pH profile at Site B.

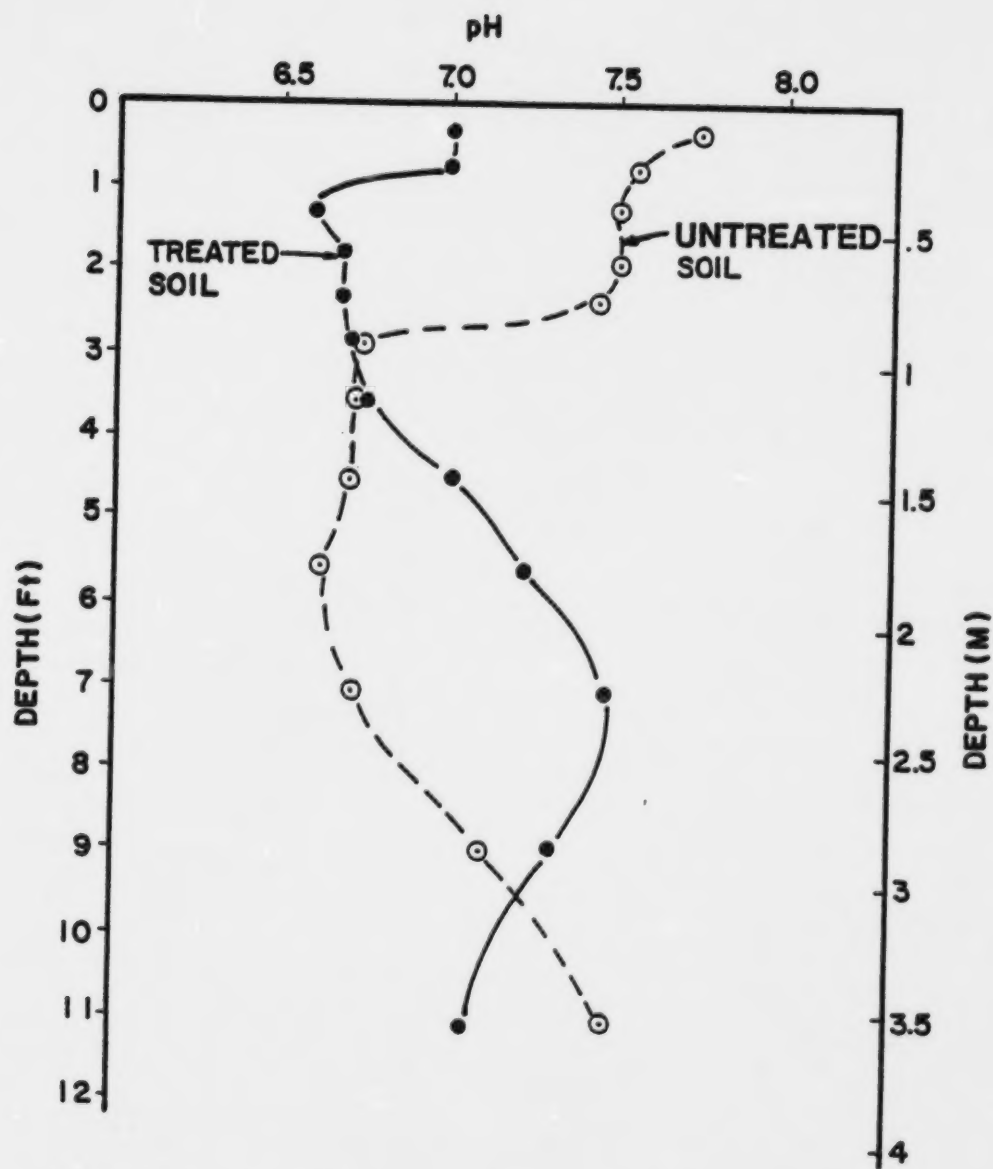


Figure 4. pH profile at Site C.

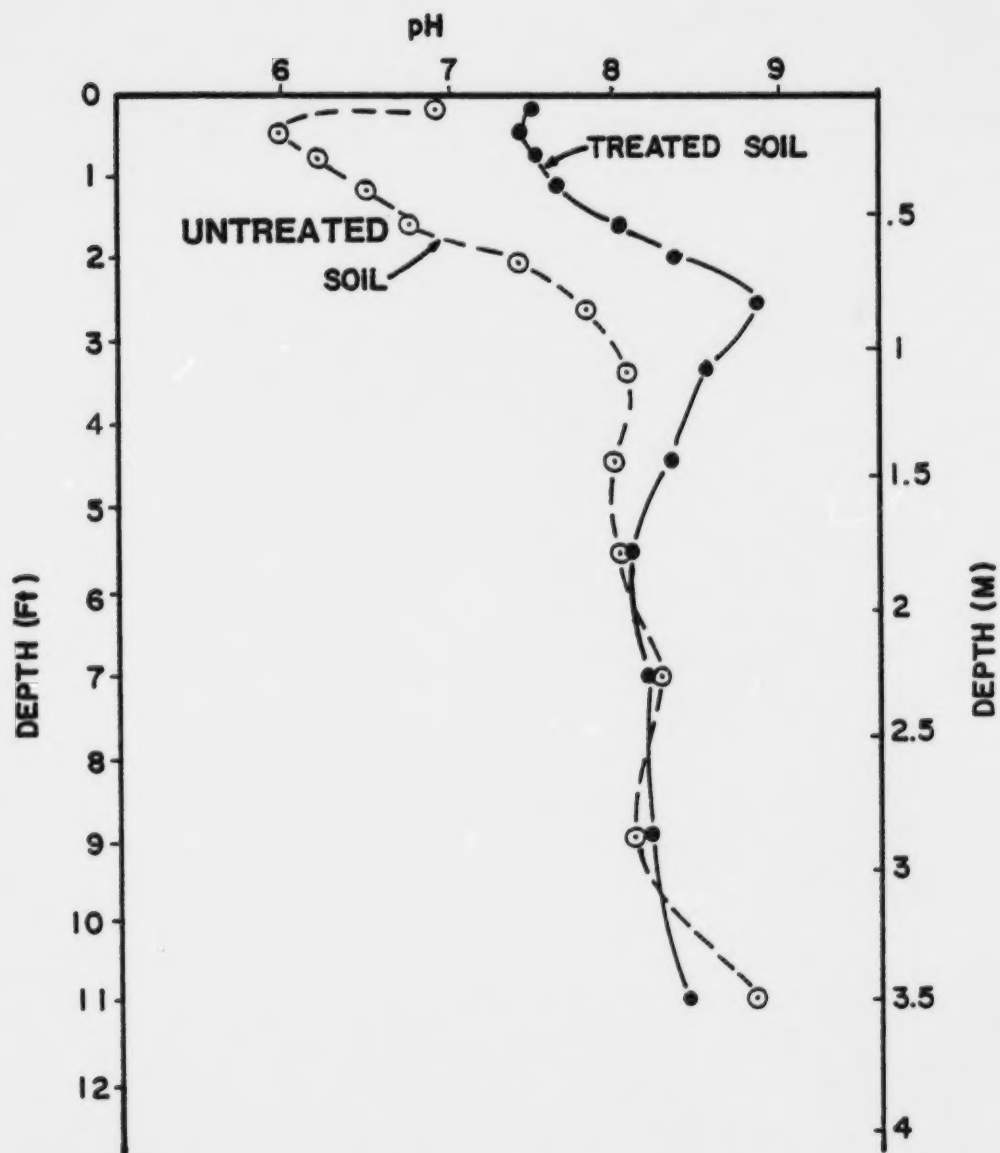


Figure 5. pH profile at Site D.

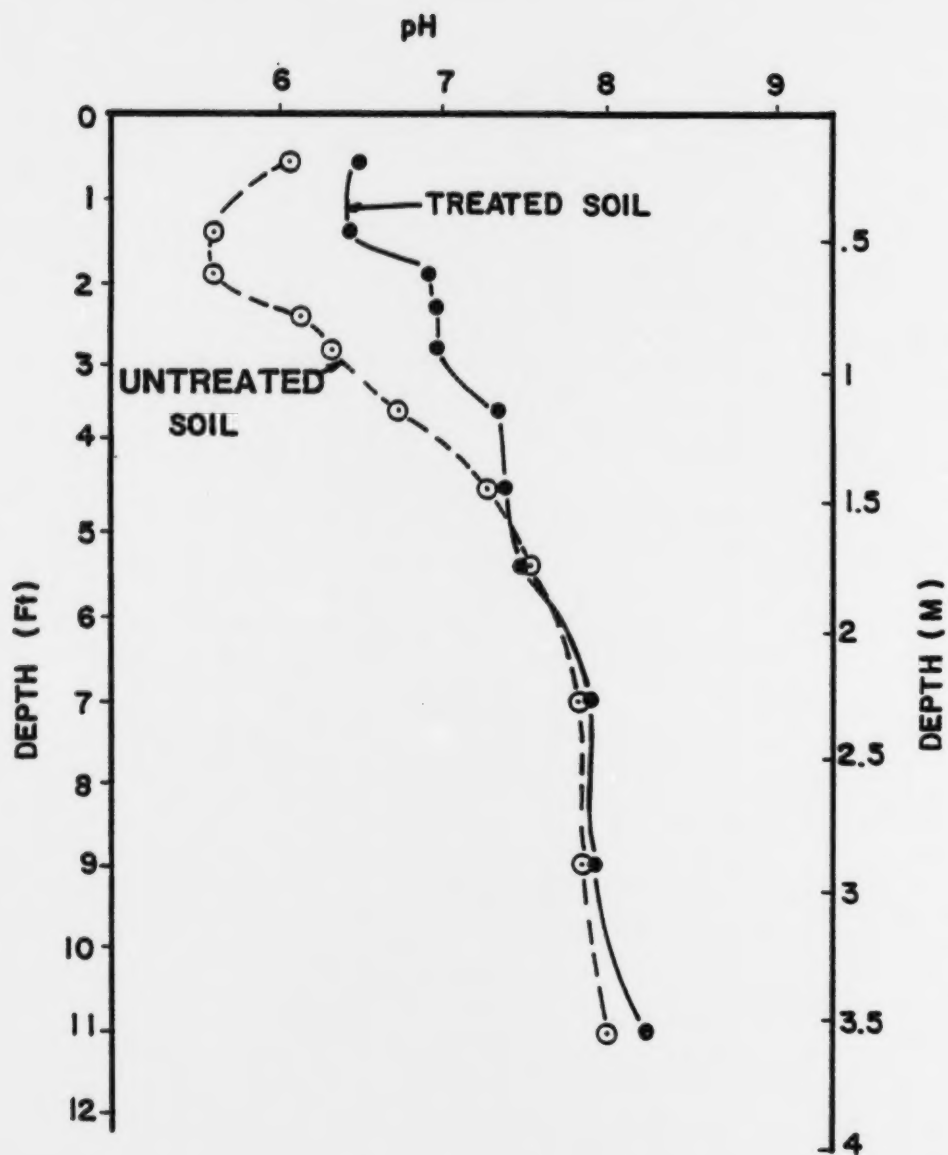


Figure 6. pH profile at Site E.

Soluble Constituents

Little can be discerned from comparing the cationic distribution of the soluble matrices, due to the complicated anionic interactions involving precipitatory mechanisms of less soluble species (Tables 12 through 16). The addition of soluble sodium salts within treatment facilities tended to decrease solution levels of background calcium and magnesium salts.

Profiles developed for the electrical conductivities are presented in Figures 7 through 11. Values generally reflected salt accumulation near the surface in sludge treated soils and downward migration in all but the more acid Site A. The extreme salinity noted between 30 to 91 cm (1 to 3 ft) of the control soil at Site D was indicative of a subsurface saline seep (a natural phenomenon).

Chloride, sulfate and nitrate anions were measured for each depth interval sampled (Tables 17 through 21) and correlated to the corresponding EC values, using the following multiple linear regression model.

$$EC = b_0 + b_1 (Cl^-) + b_2 (SO_4^{=}) + b_3 (NO_3^-)$$

To test how well the variability in EC corresponds to the three anions measured, computed values were linearly correlated to the observed values.

Regression coefficients and the coefficient of determination (r^2) comparing calculated and measured EC values are given in Table 22. The data shows that the variability of EC values can be described by a three component anion model, and EC is then adjusted to a saturated paste value. Saturated paste values better approximate salt levels at field moisture levels. Treated Site E did not conform well to a linear model ($r^2 = 0.33$). The variability in EC measured for a 1:1 soil:water ratio was somewhat attenuated when converted to a saturated paste moisture level, such that a linear model could not resolve subtle differences below the surface 46 cm (18 in).

The correlation of measured and calculated EC values for treated Site D is shown in Figure 12. While somewhat scattered about the idealized regression line, the data demonstrates a strong positive correlation, supportive of the fact that variability in EC with depth can be discerned by the changes in the respective anion concentrations. A comparison of anion concentrations averaged over depth is given in Table 23. Treated Site A shows essentially no change in either the distribution or total

Table 12 . Electrical Conductivity, pH, Soluble Cations, and Sodium Adsorption Ratio (SAR) in the Untreated and Treated Soils at Site A.

Site	Depth (cm)	Depth (in)	EC (μ mhos/cm)	pH	Soluble Salts				SAR
					Na	K	Ca	Mg	
					(meq/liter)				
A-Untreated Soil	0-15	0-6	3.5	7.9	56.0	30.0	214.0	126.0	4.3
	15-23	6-9	10.0	8.3	229.0	7.1	747.0	35.7	11.6
	23-30	9-12	19.2	8.2	306.0	1.0	13,354.0	381.0	3.7
	30-53	12-21	25.4	8.3	340.0	1.8	1,763.0	44.0	11.3
	53-76	21-30	35.7	8.4	414.0	1.8	330.0	28.6	30.9
	76-102	30-40	47.6	8.2	481.0	4.8	90.0	50.0	57.5
	102-127	40-50	21.6	8.2	363.0	3.3	70.0	33.0	50.6
	127-152	50-60	40.6	8.3	515.0	4.2	108.0	48.0	58.7
A-Treated Soil	0-15	0-6	13.8	6.6	92.0	19.4	119.0	50.0	10.0
	15-23	6-9	3.9	7.4	145.0	3.6	83.0	14.0	20.3
	23-30	9-12	14.3	7.3	180.0	1.6	13.0	9.3	53.3
	30-53	12-21	16.1	8.1	222.0	1.9	244.0	14.3	19.5
	53-76	21-30	39.2	8.1	337.0	2.0	73.0	25.5	48.0
	76-102	30-40	31.7	8.1	472.0	3.8	315.0	102.0	32.7
	102-127	40-50	42.3	8.2	425.0	5.3	288.0	83.0	31.2
	127-152	50-60	37.3	8.3	437.0	1.9	2,788.0	202.0	11.3

Table 13 . Electrical Conductivity, pH, Soluble Cations, and Sodium Adsorption Ratio (SAR) in the Untreated and Treated Soils at Site B.

Site	Depth (cm)	Depth (in)	EC ($\mu\text{mhos/cm}$)	pH	Soluble Salts				SAR
					Na	K	Ca	Mg	
					(mg/liter)				
B-Untreated Soil	0-15	0-6	2.3	4.5	5.1	<0.5	5.1	< 1.0	3.2
	15-30	6-12	2.1	4.3	3.2	<0.5	6.4	< 1.0	1.8
	30-46	12-18	1.3	5.3	3.3	<0.5	3.3	< 1.0	2.6
	46-61	18-24	1.0	5.4	3.8	<0.5	3.8	< 1.0	2.8
	61-76	24-30	0.9	5.5	3.6	<0.5	3.6	< 1.0	2.7
	76-91	30-36	1.0	5.6	3.8	<0.5	3.8	< 1.0	2.8
	91-122	36-48	0.9	5.6	3.4	<0.5	10.3	10.3	1.1
	122-152	48-60	0.5	6.2	2.6	<0.5	10.5	13.2	0.8
	152-183	60-72	0.5	6.1	2.6	<0.5	7.9	5.3	1.0
	183-244	72-96	0.9	6.3	3.1	<0.5	9.4	3.1	1.2
	244-305	96-120	1.5	7.1	4.2	<0.5	20.8	8.3	1.1
305-366	120-144	1.8	7.1	4.2	<0.5	20.8	8.3	1.1	
B-Treated Soil	0-15	0-6	6.9	5.1	5.7	5.7	54.0	31.0	0.9
	15-30	6-12	5.9	4.7	5.9	2.9	38.0	26.0	1.0
	30-46	12-18	6.4	4.8	5.8	0.8	64.0	22.0	4.3
	46-61	18-24	2.9	5.7	5.9	2.9	59.0	26.0	0.9
	61-76	24-30	4.4	5.4	7.4	<0.5	22.0	15.0	1.7
	76-91	30-36	4.4	5.1	7.4	<0.5	22.0	19.0	1.6
	91-122	36-48	1.3	5.2	5.9	<0.5	12.0	12.0	1.7
	122-152	48-60	1.8	5.4	5.6	<0.5	14.0	17.0	1.4
	152-183	60-72	1.2	5.8	5.6	<0.5	15.0	17.0	1.4
	183-244	72-96	1.5	5.6	5.4	<0.5	8.1	11.0	1.7
	244-305	96-120	0.9	6.0	4.9	<0.5	12.0	19.5	1.2
	305-366	120-144	0.9	6.2	4.9	<0.5	12.0	19.5	1.2

Table 14 . Electrical Conductivity, pH, Soluble Cations, and Sodium Adsorption Ratio (SAR) in the Untreated and Treated Soils at Site C.

Site	Depth (cm)	Depth (in)	EC (μ mhos/cm)	pH	Soluble Salts (μ eq/liter)				SAR
					Na	K	Ca	Mg	
C-Untreated Soil	0-15	0-6	9.4	7.0	47.0	6.3	250.0	19.0	4.1
	15-30	6-12	8.1	7.6	33.0	7.4	1,407.0	15.0	1.2
	30-46	12-18	3.7	7.5	26.0	3.7	8,359.0	11.0	0.4
	46-61	18-24	4.1	7.5	52.0	3.4	18,555.0	21.0	0.5
	61-76	24-30	4.8	7.4	48.0	3.0	148.0	12.0	5.5
	76-91	30-36	5.6	6.7	68.0	2.9	18.0	0.8	18.6
	91-122	36-48	7.1	6.7	94.0	2.9	26.0	8.8	22.5
	122-152	48-60	6.3	6.7	53.0	1.5	2,197.0	11.8	1.6
	152-183	60-72	5.0	6.6	38.2	1.5	88.2	14.7	5.3
	183-244	72-96	1.6	6.8	16.3	2.0	8.2	14.3	4.9
	224-305	96-120	0.9	7.2	6.2	3.1	6.2	21.9	1.7
C-Treated Soil	305-366	120-144	0.4	7.5	4.2	4.2	< 1.0	4.2	2.9
	0-15	0-6	33.3	7.0	267.0	10.0	187.0	123.0	21.4
	15-30	6-12	7.4	7.0	58.0	3.2	19.3	12.9	14.5
	30-46	12-18	3.6	6.6	33.0	3.0	6.1	3.0	15.5
	46-61	18-24	3.8	6.7	34.0	1.7	3.4	3.4	18.4
	61-76	24-30	3.7	6.7	37.0	1.9	3.7	3.7	19.2
	76-91	30-36	4.2	6.7	35.0	1.6	3.2	3.2	19.5
	91-122	36-48	3.4	6.8	38.0	3.3	3.3	3.3	21.0
	122-152	48-60	3.2	7.1	39.0	1.6	3.2	3.2	21.8
	152-183	60-72	4.7	7.3	43.0	0.5	3.3	10.0	16.7
	183-244	72-96	1.9	7.5	23.0	3.2	9.7	16.0	6.4
	244-305	96-120	2.0	7.3	20.0	3.3	10.0	20.0	5.2
	305-366	120-144	1.7	7.1	6.9	0.5	3.4	6.9	3.0

Table 15 . Electrical Conductivity, pH, Soluble Cations, and Sodium Adsorption Ratio (SAR) in the Untreated and Treated Soils at Site D.

Site	Depth (cm-)	Depth (in)	EC ($\mu\text{mhos/cm}$)	pH	Soluble Salts				SAR
					Na	K	Ca	Mg	
					(meq/liter)				
D-Untreated Soil	0-10	0-4	2.8	6.9	3.3	6.6	23.0	3.3	0.9
	10-20	4-8	1.8	6.0	3.2	3.2	16.0	32.0	0.6
	20-30	8-12	2.9	6.2	31.0	2.1	42.0	21.0	5.5
	30-46	12-18	7.7	6.6	68.0	1.3	34.0	25.0	12.6
	46-61	18-24	14.7	6.8	127.0	0.0	12.0	10.0	38.5
	61-76	24-30	14.6	7.4	127.0	0.0	4.1	4.1	63.5
	76-91	30-36	11.1	7.3	153.0	2.2	6.7	6.7	58.8
	91-122	36-48	10.2	8.0	102.0	0.0	4.1	2.0	60.0
	122-152	48-60	9.8	7.9	105.0	2.4	24.0	20.0	22.3
	152-183	60-72	10.0	8.0	92.0	2.6	37.0	24.0	16.7
	183-244	72-96	6.1	8.3	88.0	2.4	34.0	17.0	17.5
	244-305	96-120	7.4	8.2	61.0	2.6	34.0	24.0	11.3
	305-366	120-144	5.2	8.8	48.0	0.0	6.9	3.4	20.9
D-Treated Soil	0-10	0-4	8.2	7.5	54.0	2.6	21.0	13.0	3.2
	10-20	4-8	8.4	7.4	47.0	2.3	28.0	19.0	9.8
	20-30	8-12	4.8	7.5	39.0	2.1	33.0	22.0	7.5
	30-46	12-18	4.9	7.7	51.0	2.2	36.0	24.0	9.3
	46-61	18-24	4.9	8.0	24.0	2.2	36.0	27.0	4.3
	61-76	24-30	3.8	8.2	40.0	2.2	67.0	37.0	5.5
	76-91	30-36	2.8	8.9	42.0	2.3	44.0	44.0	6.4
	91-122	36-48	7.5	8.5	55.0	2.3	23.0	25.0	11.2
	122-152	48-60	8.4	8.3	67.0	2.2	44.0	42.0	10.1
	152-183	60-72	8.8	8.1	84.0	2.3	33.0	30.0	15.0
	183-244	72-96	8.3	8.2	69.0	2.7	23.0	22.0	13.8
	244-305	96-120	9.0	8.2	17.0	0.0	10.3	3.4	6.5
	305-366	120-144	5.2	8.4	59.0	0.0	7.4	3.7	25.6

Table 16. Electrical Conductivity, pH, Soluble Cations, and Sodium Adsorption Ratio (SAR) in the Untreated and Treated Soils at Site U.

Site	Depth (cm)	Depth (in)	EC (mmhos/cm)	pH	Soluble Salts				SAR
					Na	K	Ca	Mg	
					(meq/liter)				
E-Untreated Soil	0-30	0-12	1.3	6.1	1.8	<0.5	29.1	10.9	0.4
	30-46	12-13	1.1	5.7	1.8	<0.5	29.8	12.3	0.4
	46-61	18-24	1.1	5.7	12.3	<0.5	15.3	12.3	3.3
	61-76	24-30	1.2	6.1	13.3	1.7	15.0	11.7	3.6
	76-91	30-36	1.1	6.2	15.3	<0.5	18.5	16.9	3.6
	91-122	36-48	1.0	6.6	18.8	1.6	21.9	21.9	4.0
	122-152	48-60	0.7	7.1	7.1	1.3	21.0	22.4	1.5
	152-133	60-72	0.7	7.3	22.5	<0.5	18.8	18.8	5.2
	133-244	72-96	0.5	7.7	24.3	1.4	35.7	47.1	3.8
	244-305	96-120	0.6	7.9	27.5	1.4	27.5	36.2	4.9
	305-366	120-144	0.6	7.9	30.1	1.4	42.5	56.2	4.3
E-Treated Soil	0-30	0-12	2.3	6.5	31.0	1.7	39.6	24.1	5.5
	30-46	12-18	2.5	6.4	20.0	1.7	31.7	26.7	3.7
	46-61	18-24	2.9	6.8	32.2	1.6	32.2	29.0	5.8
	61-76	24-30	1.8	6.9	30.3	1.5	27.2	24.2	6.0
	76-91	30-36	1.3	7.3	7.6	1.5	47.0	50.0	1.1
	91-122	36-48	1.3	7.3	9.0	1.5	34.3	40.2	1.5
	122-152	48-60	1.3	7.2	32.4	1.5	35.3	47.0	5.1
	152-133	60-72	1.1	7.7	31.3	1.5	25.4	32.8	5.8
	133-244	72-96	1.1	7.3	33.3	1.5	34.3	45.5	5.3
	244-305	96-120	1.0	7.9	34.4	1.6	31.3	39.1	4.1
	305-366	120-144	0.9	8.2	32.3	1.6	32.3	39.1	5.5

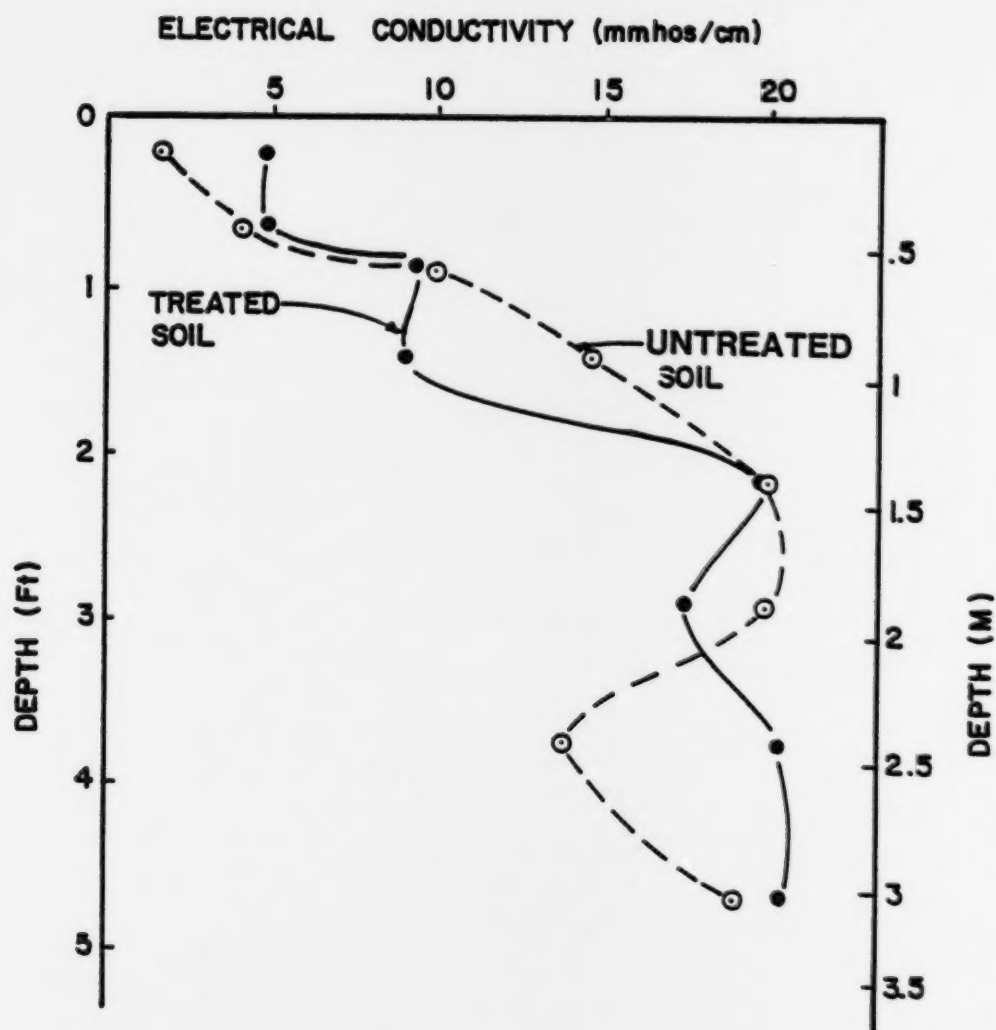


Figure 7. EC profile at Site A.

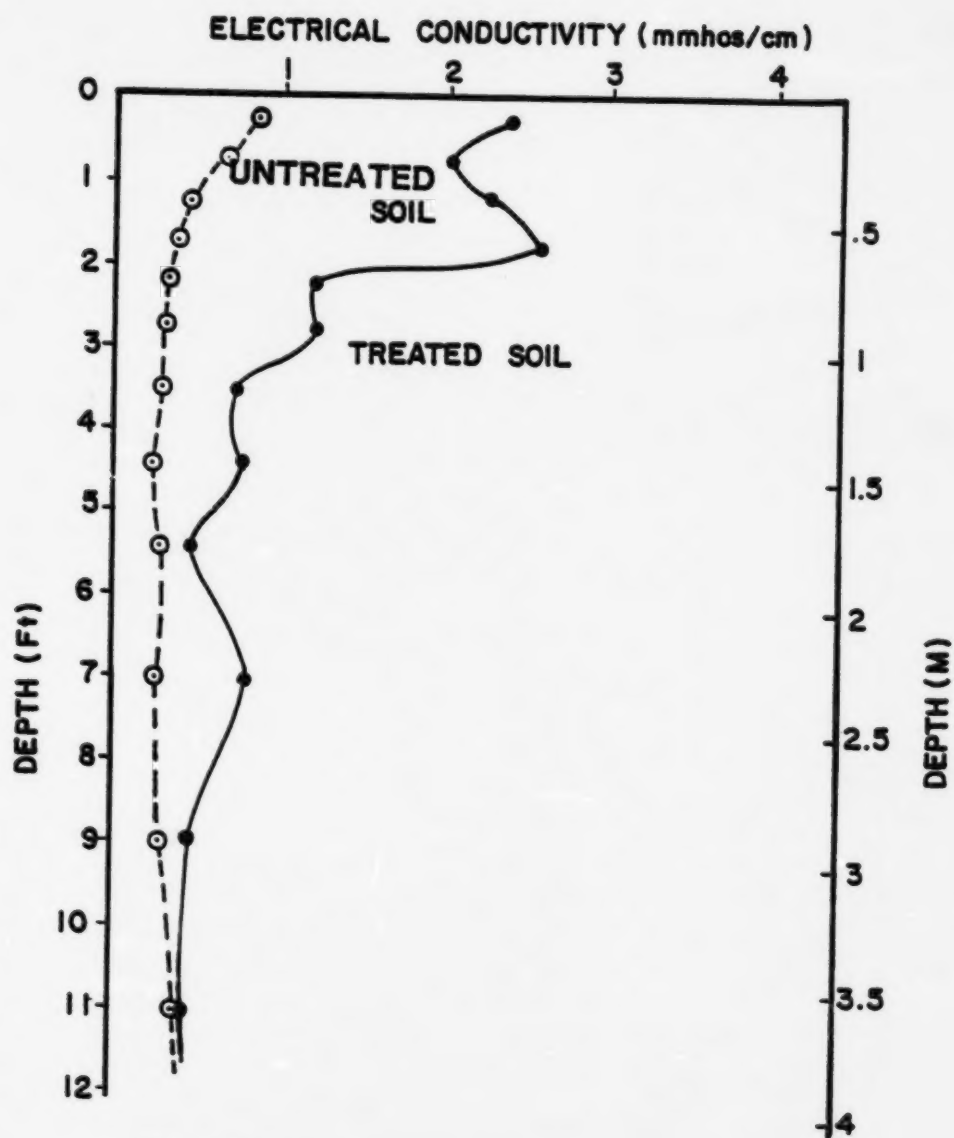


Figure 8. EC profile at Site B.

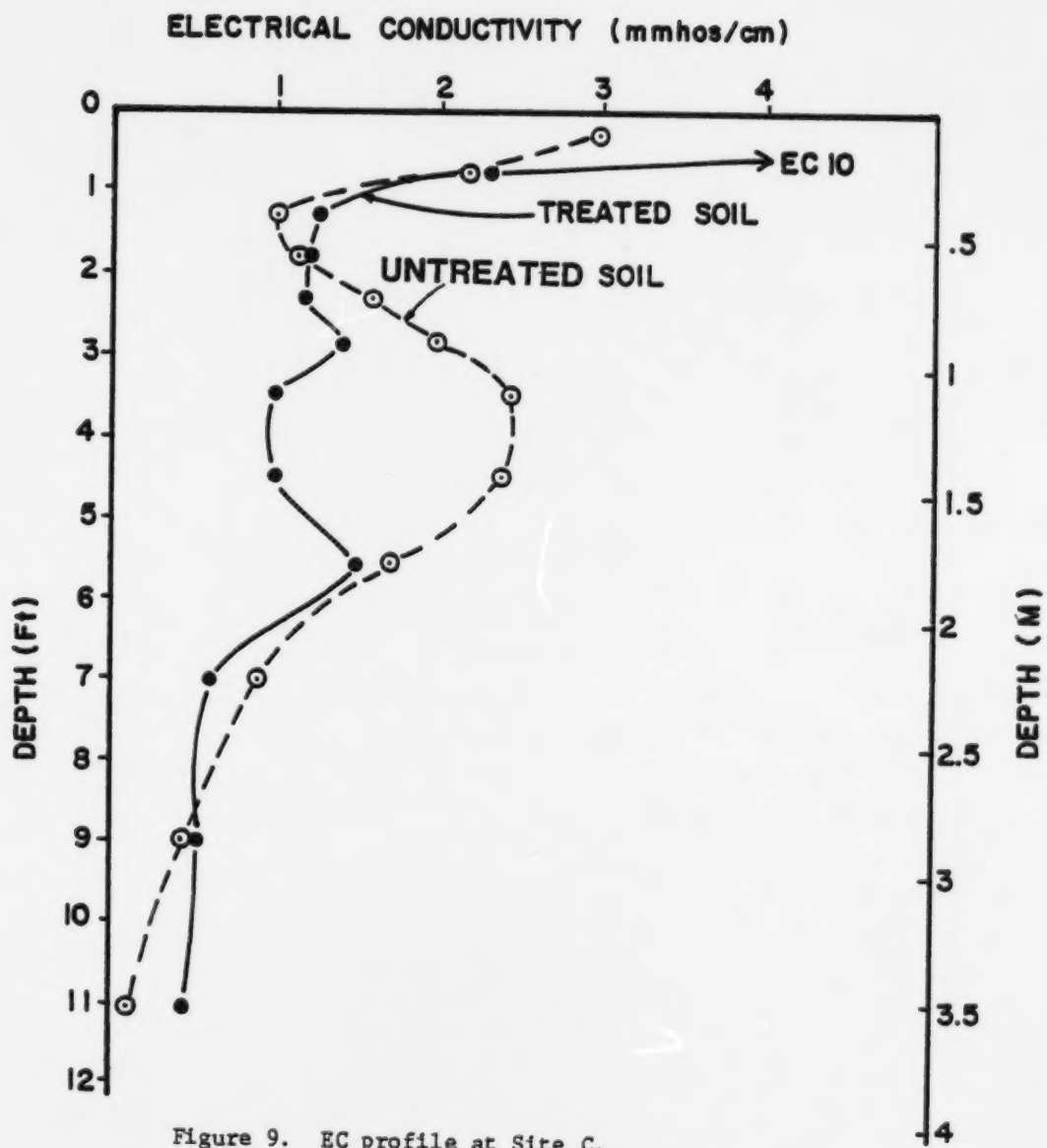


Figure 9. EC profile at Site C.

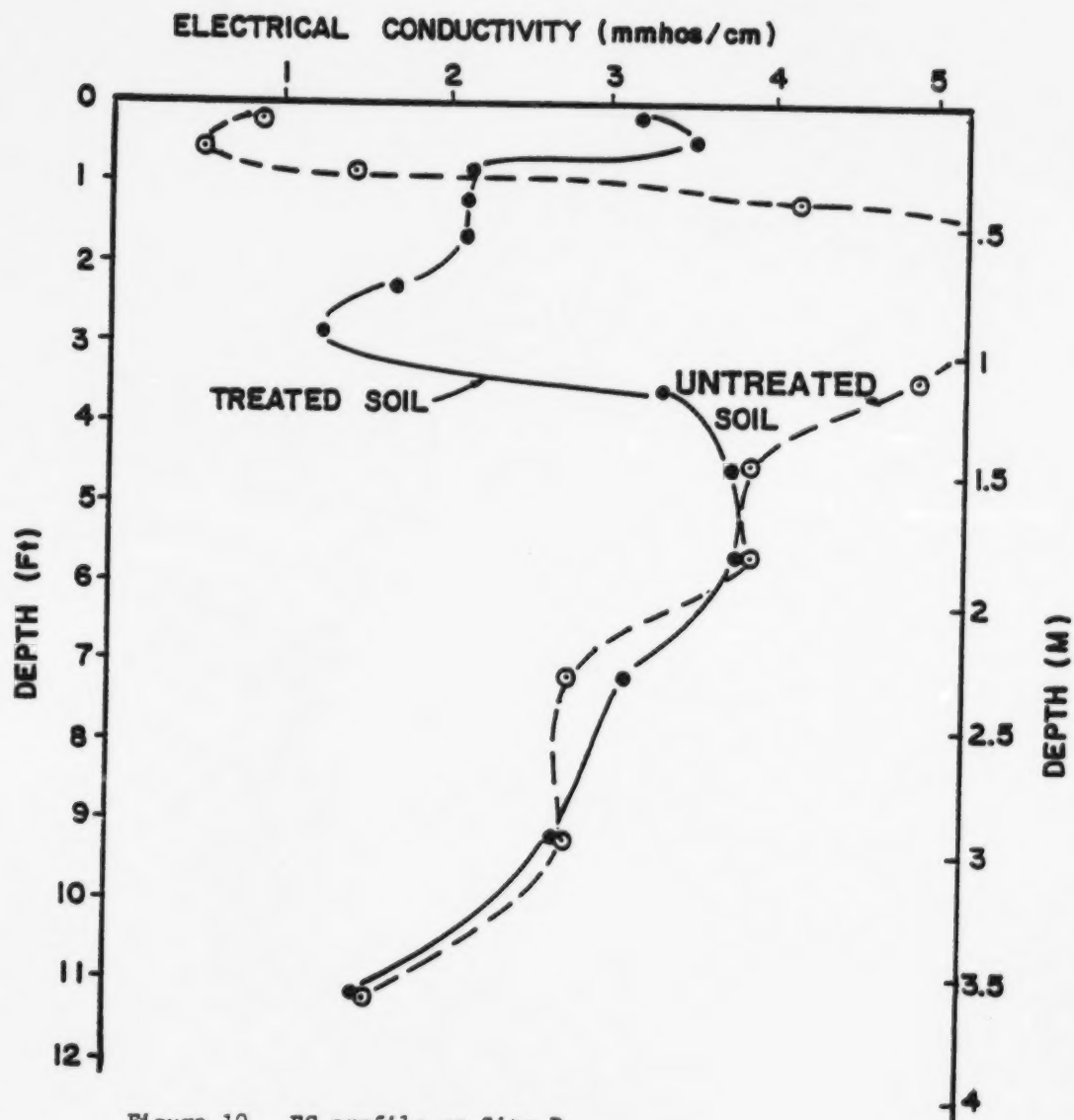


Figure 10.. EC profile at Site D.

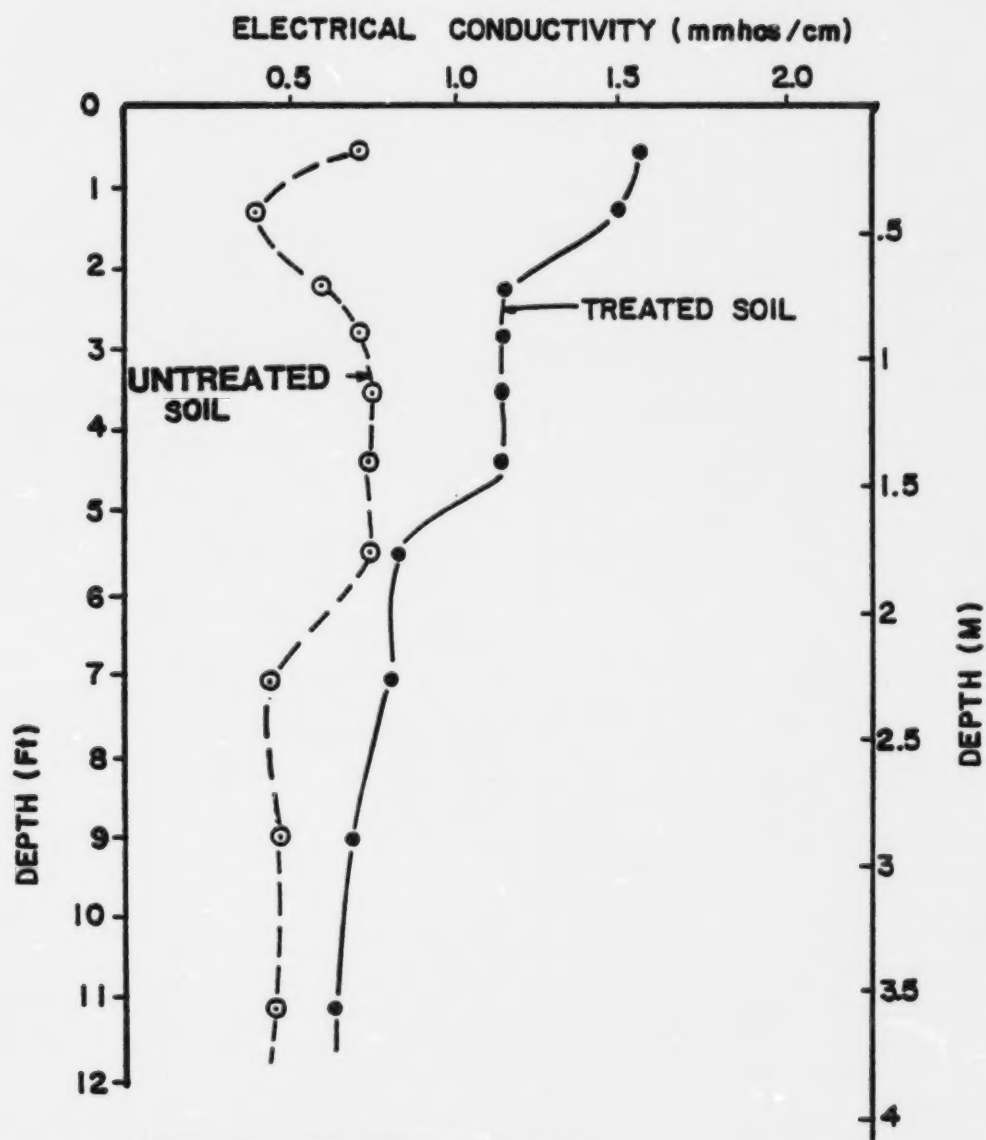


Figure 11. EC profile at Site E.

Table 17. Soluble Anions in the Untreated and Treated Soils at Site A.

Site	Depth (cm)	Depth (in)	Anion Concentration(meq/liter)†		
			Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
A-Untreated Soil	0-15	0-6	1.3	191	2.2
	15-23	6-9	3.3	106	1.4
	23-30	9-12	2.0	147	0.3
	30-53	12-21	1.7	212	0.3
	53-76	21-30	2.0	284	0.3
	76-102	30-40	2.0	564	1.1
	102-127	40-50	1.3	292	1.5
	127-152	50-60	1.7	380	0.5
A-Treated	0-15	0-6	5.4	234	0.8
	15-23	6-9	3.3	122	0.9
	23-30	9-12	3.1	148	0.8
	30-53	12-21	3.4	198	0.6
	53-76	21-30	3.3	335	0.5
	76-102	30-40	2.9	356	0.7
	102-127	40-50	3.0	326	1.1
	127-152	50-60	2.6	344	0.7

† Values relative to a saturated paste extract.

Table 18. Soluble Anions in the Untreated and Treated Soils at Site 8.

Site	Depth (cm)	Depth (in)	Anion Concentration(meq/liter) [†]		
			Cl ⁻	SO ₄ ⁼	NO ₃ ⁻
B-Untreated Soil	0-15	0-6	0.9	13.6	0.4
	15-30	6-12	0.5	10.4	0.4
	30-46	12-18	0.7	10.0	0.3
	46-61	18-24	0.7	8.6	0.4
	61-76	24-30	0.5	10.4	0.5
	76-91	30-36	0.6	11.6	0.3
	91-122	36-48	0.6	10.6	0.5
	122-152	48-60	0.4	6.6	0.4
	152-183	60-72	0.4	6.7	0.4
	183-244	72-96	0.4	7.8	0.6
	244-305	96-120	0.8	7.8	1.0
	305-366	120-144	0.8	10.4	0.9
B-Treated Soil	0-15	0-6	2.3	76.6	1.5
	15-30	6-12	2.3	45.4	1.1
	30-46	12-18	3.4	41.6	1.6
	46-61	18-24	3.7	66.2	3.6
	61-76	24-30	3.0	36.4	0.9
	76-91	30-36	3.3	38.0	0.9
	91-122	36-48	1.9	16.8	0.6
	122-152	48-60	2.0	22.9	0.6
	152-183	60-72	2.2	11.8	0.6
	183-244	72-96	2.2	13.8	0.5
	244-305	96-120	1.9	11.2	0.5
	305-366	120-144	1.9	9.2	0.5

[†] Values relative to a saturated paste extract.

Table 19. Soluble Anions in the Untreated and Treated Soils at Site C.

Site	Depth (cm)	Depth (in)	Anion Concentration(meq/liter) [†]		
			Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻
C-Untreated Soil	0-15	0-6	39.8	40.8	8.0
	15-30	6-12	29.8	20.3	11.1
	30-46	12-18	23.7	7.6	0.9
	46-61	18-24	34.8	12.2	1.1
	61-76	24-30	32.5	4.3	0.8
	76-91	30-36	54.0	6.3	1.0
	91-122	36-48	85.9	2.0	1.0
	122-152	48-60	86.2	2.0	0.9
	152-183	60-72	54.4	2.0	0.7
	183-244	72-96	23.5	2.1	0.5
	244-305	96-120	10.2	2.2	0.4
	305-366	120-144	3.5	0.9	0.5
C-Treated Soil	0-15	0-6	199.0	170.0	3.3
	15-30	6-12	39.8	37.2	1.8
	30-46	12-18	25.6	13.4	1.1
	46-61	18-24	38.0	14.7	1.7
	61-76	24-30	38.0	16.2	1.2
	76-91	30-36	28.6	4.5	1.1
	91-122	36-48	20.2	9.8	1.1
	122-152	48-60	19.5	6.9	1.1
	152-183	60-72	30.4	10.5	1.1
	183-244	72-96	14.5	7.0	0.7
	244-305	96-120	17.2	2.3	0.8
	305-366	120-144	14.1	2.4	0.6

[†] Values relative to a saturated paste extract.

Table 20. Soluble Anions in the Untreated and Treated Soils at Site D.

Site	Depth (cm)	Depth (in)	Anion Concentration(meq/liter) [†]		
			Cl ⁻	SO ₄ ⁼	NO ₃
D-Untreated Soil	0-10	0-4	3.3	5.9	5.7
	10-20	4-8	3.9	3.4	2.2
	20-30	8-12	13.2	2.8	11.0
	30-46	12-18	48.4	16.8	4.1
	46-61	18-24	102.0	41.2	2.1
	61-76	24-30	126.0	32.6	8.1
	76-91	30-36	139.0	14.2	10.0
	91-122	36-48	111.0	13.4	9.0
	122-152	48-60	101.0	9.6	11.1
	152-183	60-72	96.3	10.1	13.2
	183-244	72-96	67.5	10.4	11.2
	244-305	96-120	72.8	12.6	12.4
	305-366	120-144	30.5	4.6	17.0
D-Treated Soil	0-10	0-4	15.3	28.5	3.1
	10-20	4-8	14.4	26.9	18.7
	20-30	8-12	12.5	6.2	13.7
	30-46	12-18	11.5	9.6	19.6
	46-61	18-24	12.1	9.1	19.9
	61-76	24-30	18.3	9.1	38.4
	76-91	30-36	24.6	13.0	28.2
	91-122	36-48	34.1	15.2	8.3
	122-152	48-60	35.8	12.1	9.6
	152-183	60-72	62.1	9.4	9.2
	183-244	72-96	61.4	11.2	15.4
	244-305	96-120	51.1	6.8	21.4
	305-366	120-144	29.8	9.4	12.6

[†] Values relative to a saturated paste extract.

Table 21. Soluble Anions in the Untreated and Treated Soils at Site E.

Site	Depth (cm)	Depth (in)	Anion Concentration(meq/liter) [†]		
			Cl ⁻	SO ₄ ⁼	NO ₃ ⁻
E-Untreated Soil	0-30	0-12	1.6	2.7	0.2
	30-46	12-18	1.4	2.6	0.2
	46-61	18-24	2.0	9.0	0.2
	61-76	24-30	2.0	4.6	0.2
	76-91	30-36	2.0	4.7	0.3
	91-122	36-48	1.9	7.0	0.3
	122-152	48-60	1.3	4.0	0.3
	152-183	60-72	0.9	3.8	0.1
	183-244	72-96	1.0	3.2	0.2
	244-305	96-120	1.1	3.2	0.3
	305-366	120-144	1.1	2.0	0.5
E-Treated Soil	0-30	0-12	9.9	33.6	0.6
	30-46	12-18	11.0	4.9	0.3
	46-61	18-24	3.2	3.6	0.4
	61-76	24-30	4.6	9.0	0.2
	76-91	30-36	6.6	3.4	0.2
	91-122	36-48	3.4	6.4	0.2
	122-152	48-60	2.2	4.4	0.3
	152-183	60-72	4.5	3.4	0.2
	183-244	72-96	3.2	2.4	0.4
	244-305	96-120	6.7	1.2	0.3
	305-366	120-144	6.7	1.2	0.4

[†] Values relative to a saturated paste extract.

Table 22. Regression Coefficients and Corresponding Coefficient of Determination.

Site	Constant	Anion Coefficient			r^2
		Cl ⁻	SO ₄ ⁼	NO ₃	
A-Untreated	9.0	1.4	0.10	-9.2	0.98
A-Treated	-0.3	-3.9	0.12	+9.4	0.91
B-Untreated	-1.07	0.75	0.16	0.40	0.77
B-Treated	-1.71	1.46	0.12	-2.26	0.86
C-Untreated	0.21	0.08	0.10	0.32	0.96
C-Treated	0.48	0.04	0.03	1.37	0.99
D-Untreated	0.4	0.03	0.29	0.22	0.87
D-Treated	5.07	0.03	0.14	-0.10	0.75
E-Untreated	0.40	0.67	-0.06	-1.04	0.85
E-Treated	1.18	0.08	0.03	-0.35	0.33

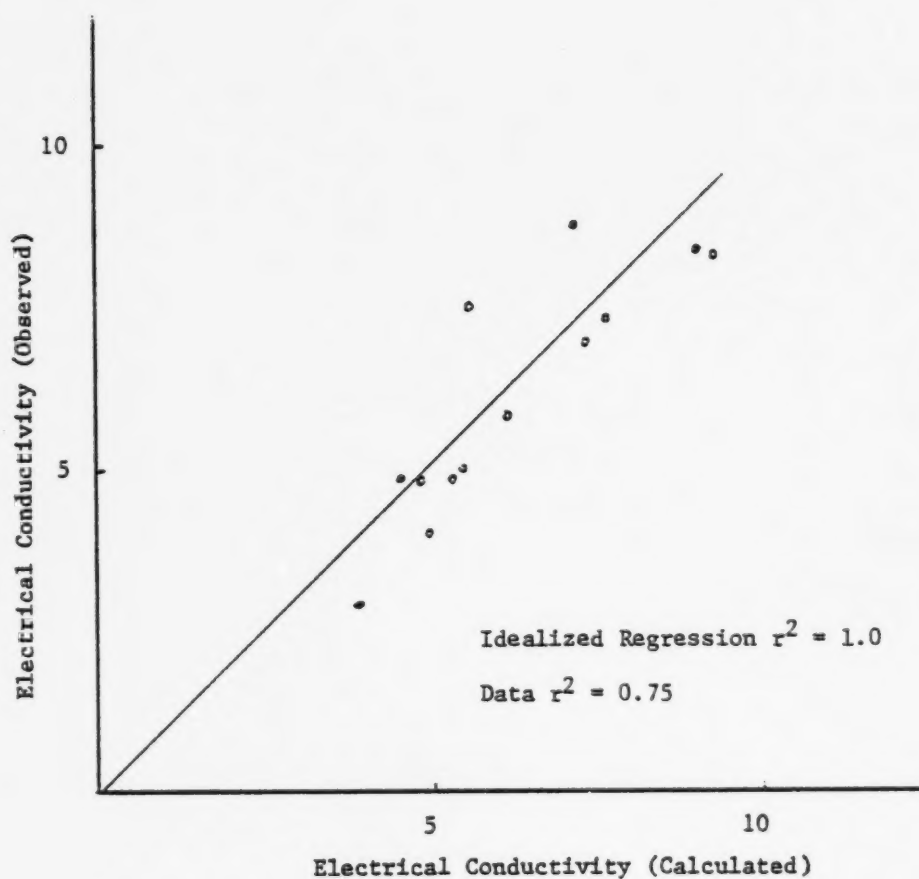


Figure 12. Correlation of observed and calculated EC values for treated site D.

Table 23. Mean Cl^- , SO_4^{2-} , and NO_3^- Values Averaged Over Depth for Both Treated and Untreated Soils.

Site	Anion		
	Cl^-	SO_4^{2-}	NO_3^-
	mg/liter		
A-Untreated	1.91	272	0.95
A-Treated	3.38	258	0.76
B-Untreated	0.67	9.54	0.54
B-Treated	2.51	31.6	1.08
C-Untreated	40.3	8.58	2.24
C-Treated	40.4	41.2	1.71
D-Untreated	60.8	13.7	9.01
D-Treated	29.5	12.8	16.8
E-Untreated	1.48	4.25	0.25
E-Treated	6.00	6.68	0.31

salt loading, as reflected in the EC profile (Figure 7). The principal salinity increase at treated Site B can be attributed to chloride and sulfate salts. Salt loading at Site C is attributed to sulfates. The saline seep sample for comparative assay at Site D somewhat pales the slight increase in the nitrate level. Chloride dominates the total salt increase at treated Site E; although, there was a significant sulfate increase noted at the 0-30 cm (0-12 in) depth interval.

While it is always tenuous to extrapolate data of this nature, it appears that the impact of salt loading from land treatment of refinery waste is low.

Heavy Metal Distribution

In general, trace minerals (which involve some heavy metals), tend to have an enhanced soluble phase in high organic containing soils - principally through chelation mechanisms. Mobility then is controlled by soil surface adsorption and precipitatory mechanisms.

Metal analyses with depth are presented in Tables 24 through 28. Normal concentrations and ranges of trace elements in soils are given in Table 29. Chromium was found to be significantly higher in all treated surface horizons. Lead was higher in all but treated Site E, compared to untreated soils. The only other element of significance was the mercury accumulated at treated Site B.

While chromium, lead and mercury at the one site were accumulated in significant quantities, only the mercury level could be considered as abnormally high relative to naturally occurring metal concentrations. Van Loon (1974) reported that the concentration of Hg in soil that is toxic to plants was greater than 10 ppm, and thus further application of Hg containing waste should probably be curtailed if plant growth is planned. There was some evidence of downward migration of chromium at treated Site B, to the 76 to 91 cm (30 to 36 in) depth interval. The apparent migration is attributed to the more acidic profile and a correspondingly higher organic phase.

Metal concentrations at all treated facilities were generally within ranges considered normal for soils. There would thus be no potential for an adverse impact anticipated from present loadings at any of the treated sites.

Table 24. Total Metal Contents with Depth for Untreated and Treated Soil at Site A in ppm.

Site	Depth (cm)	Depth (in)	As	Cd	Cr	Hg	Pb	Ni	V
A-Untreated Soil	0-15	0-6	1.2	1.8	29.4	0.6	23.5	17.6	67.6
	15-23	6-9	9.2	2.4	32.3	0.6	29.4	23.5	67.6
	23-30	9-12	8.3	1.9	27.8	0.6	27.8	22.2	63.9
	30-53	12-21	1.6	2.2	25.0	0.6	27.8	19.4	77.8
	53-76	21-30	0.9	2.2	28.1	0.6	31.3	21.9	71.9
	76-102	30-40	3.7	1.8	29.4	1.2	29.4	23.5	58.8
	102-127	40-50	4.6	1.8	26.5	1.2	29.4	20.6	52.9
	127-152	50-60	1.2	1.7	25.0	0.6	22.2	19.4	55.6
A-Treated Soil	0-15	0-6	1.7	2.1	182.4	1.2	50.0	11.8	44.1
	15-23	6-9	1.2	2.1	44.1	1.2	29.4	17.6	58.8
	23-30	9-12	3.7	1.8	26.5	0.6	29.4	17.6	58.8
	30-53	12-21	8.8	2.1	26.5	1.8	29.4	17.6	67.6
	53-76	21-30	0.2	2.2	28.1	0.6	31.3	15.6	62.5
	76-102	30-40	1.1	2.1	42.1	1.1	31.6	15.8	65.8
	102-127	40-50	6.3	2.3	41.9	1.1	28.8	23.6	78.5
	127-152	50-60	6.9	2.0	31.9	1.2	28.9	17.3	57.8

Table 25. Total Metal Contents with Depth for Untreated and Treated Soil at Site B in ppm.

Site	Depth (cm)	Depth (in)	As	Cd	Cr	Hg	Pb	Ni	V
B-Untreated Soil	0-15	0-6	1.6	2.1	35.5	< 0.5	17.7	28.4	106.4
	15-30	6-12	< 0.2	1.3	19.1	< 0.5	12.7	22.3	95.5
	30-46	12-18	0.9	0.9	20.7	< 0.5	6.0	20.9	119.7
	46-61	18-24	< 0.2	1.2	20.4	< 0.5	5.8	23.4	117.0
	61-76	24-30	< 0.2	0.9	23.1	< 0.5	5.8	23.1	86.7
	76-91	30-36	1.7	2.1	18.1	< 0.5	6.0	24.1	120.5
	91-122	36-48	< 0.2	1.2	12.2	< 0.5	6.1	21.3	91.5
	122-152	48-60	3.7	1.5	25.4	< 0.5	10.2	35.5	152.3
	152-183	60-72	2.6	1.3	33.0	< 0.5	10.2	35.5	101.5
	183-244	72-96	1.5	1.5	32.8	< 0.5	12.6	30.3	126.3
	244-305	96-120	1.5	1.0	22.7	< 0.5	10.1	30.3	75.8
	305-366	120-144	1.1	1.3	27.8	< 0.5	10.1	32.8	75.8
B-Treated Soil	0-15	0-6	4.3	2.1	191.0	10.6	67.6	41.1	117.6
	15-30	6-12	2.7	2.2	186.3	11.2	71.4	40.4	124.2
	30-46	12-18	4.8	1.6	78.9	3.3	36.2	32.8	131.6
	46-61	18-24	1.9	1.3	44.9	1.9	16.0	28.8	128.2
	61-76	24-30	2.0	1.1	44.9	1.1	14.0	28.1	84.3
	76-91	30-36	2.6	1.5	73.9	0.9	14.3	35.5	88.8
	91-122	36-48	1.4	2.0	37.4	0.6	11.5	25.9	86.2
	122-152	48-60	3.4	1.5	40.7	< 0.5	11.6	26.2	87.2
	152-183	60-72	2.3	1.5	25.8	< 0.5	12.9	30.9	103.1
	183-244	72-96	0.7	1.8	27.9	< 0.5	12.7	35.5	101.5
	244-305	96-120	< 0.2	2.6	33.2	< 0.5	20.4	38.3	127.6
	305-366	120-144	3.0	1.8	30.6	< 0.5	17.9	40.8	102.0

Table 26. Total Metal Contents with Depth for Untreated and Treated Soil at Site C in ppm.

Site	Depth (cm)	Depth (in)	As	Cd	Cr	Hg	Pb	Ni	V
C-Untreated Soil	0-15	0-6	7.8	2.4	21.0	1.6	34.2	13.1	34.2
	15-30	6-12	4.1	1.4	19.2	1.6	32.8	10.9	27.4
	30-46	12-18	3.5	0.5	18.4	1.6	13.2	2.6	26.3
	46-61	18-24	3.1	1.8	15.0	1.6	18.0	6.0	24.0
	61-76	24-30	3.5	1.1	13.1	1.1	13.1	5.3	21.0
	76-91	30-36	3.5	1.1	10.6	1.6	5.3	10.6	79.4
	91-122	36-48	3.1	1.3	13.2	1.1	< 5.0	7.9	52.9
	122-152	48-60	3.5	1.6	16.0	1.1	5.3	8.0	53.2
	152-183	60-72	2.8	1.3	13.4	2.1	5.3	8.0	53.5
	183-244	72-96	4.0	1.9	16.3	1.6	5.4	13.6	54.3
	244-305	96-120	3.6	1.1	16.0	3.2	10.6	8.0	53.2
	305-366	120-144	3.4	1.0	7.7	1.6	5.1	5.1	25.6
C-Treated Soil	0-30	0-12	10.3	2.6	109.4	1.6	57.3	31.3	78.1
	30-46	12-18	8.4	0.8	16.9	1.1	14.1	11.2	56.2
	46-61	18-24	3.7	1.1	10.9	0.5	11.7	8.2	27.3
	61-76	24-30	2.8	1.1	13.4	1.1	10.7	8.1	53.8
	76-91	30-36	2.8	1.3	16.1	0.5	5.4	8.1	53.8
	91-122	36-48	2.4	1.1	13.6	0.5	5.4	8.1	54.3
	122-152	48-60	2.0	1.1	16.3	0.5	10.9	5.4	54.3
	152-183	60-72	2.0	0.8	13.8	0.5	11.0	5.5	55.2
	183-244	72-96	4.0	0.9	11.9	0.6	5.9	5.9	29.8
	244-305	96-120	3.2	1.4	13.6	0.5	10.9	8.1	54.3
	305-366	120-144	2.4	1.4	16.2	1.1	10.8	8.1	54.1
	366-427	144-168	3.6	1.1	5.3	0.5	10.6	5.3	26.6

Table 27. Total Metal Contents with Depth for Untreated and Treated Soil at Site D in ppm.

Site	Depth (cm)	Depth (in)	As	Cd	Cr	Hg	Pb	Ni	V
D-Untreated Soil	0-10	0-4	< 0.2	1.3	12.9	0.5	18.1	2.6	25.9
	10-20	4-8	0.6	1.0	7.7	0.5	18.0	5.2	25.8
	20-30	8-12	< 0.2	1.4	17.1	1.1	20.0	8.6	57.1
	30-46	12-18	< 0.2	1.9	19.5	1.1	26.0	13.0	65.1
	46-61	18-24	< 0.2	1.9	19.3	1.1	27.6	13.8	55.2
	61-76	24-30	< 0.2	1.9	16.2	1.1	27.0	13.5	54.0
	76-91	30-36	< 0.2	0.8	16.7	1.1	14.0	11.2	36.3
	91-122	36-48	< 0.2	1.1	16.0	1.6	13.4	10.7	53.4
	122-152	48-60	< 0.2	1.1	13.4	1.1	13.4	8.0	34.7
	152-183	60-72	< 0.2	1.1	16.0	1.1	13.4	8.0	34.7
	183-244	72-96	< 0.2	1.9	10.8	1.1	18.9	10.8	34.7
	244-305	96-120	< 0.2	1.3	10.7	1.1	13.4	8.1	34.7
	305-366	120-144	< 0.2	1.8	7.9	1.1	21.2	2.6	13.2
D-Treated Soil	0-10	0-4	< 0.2	1.6	31.6	3.7	63.2	13.2	34.2
	10-20	4-8	1.1	1.6	18.4	3.2	34.2	13.2	26.3
	20-30	8-12	< 0.2	1.6	13.2	1.6	21.1	10.5	26.3
	30-46	12-18	3.0	0.3	15.8	1.1	21.1	15.8	26.3
	46-61	18-24	< 0.2	1.6	15.8	1.1	26.3	10.5	26.3
	61-76	24-30	< 0.2	1.8	15.8	1.1	34.2	7.9	21.1
	76-91	30-36	< 0.2	1.8	10.5	2.1	26.3	7.9	21.1
	91-122	36-48	< 0.2	1.6	15.8	1.1	26.3	7.9	34.2
	122-152	48-60	< 0.2	1.8	15.8	1.1	26.3	7.9	34.2
	152-183	60-72	< 0.2	1.6	10.5	2.1	15.8	7.9	34.2
	183-244	72-96	< 0.2	0.3	16.7	1.1	16.7	1.4	27.8
	244-305	96-120	< 0.2	0.5	10.5	1.1	15.8	1.3	13.1
	305-366	120-144	< 0.2	1.6	7.9	1.1	21.1	1.3	7.9

Table 28. Total Metal Contents with Depth for Untreated and Treated Soil at Site C in ppm.

Site	Depth (cm.)	Depth (in.)	As	Cd	Cr	Hg	Pb	Ni	V
E-Untreated Soil	0-30	0-12	4.8	2.7	41.0	1.1	95.6	30.0	109.3
	30-46	12-18	3.7	2.4	29.9	1.1	33.3	21.7	108.7
	46-61	18-24	3.3	2.7	41.2	1.6	38.5	30.2	137.4
	61-76	24-30	3.4	2.5	38.5	1.1	38.5	30.2	137.4
	76-91	30-36	6.3	2.5	41.9	1.1	47.5	36.3	139.7
	91-122	36-48	2.9	2.5	47.0	1.1	47.0	35.9	193.4
	122-152	60-72	4.8	2.5	27.6	0.6	27.6	22.1	110.5
	152-183	60-72	6.3	2.5	44.4	0.6	44.4	30.6	194.4
	183-244	72-96	<0.2	3.0	38.7	0.6	38.7	31.1	138.1
	244-305	96-120	4.8	3.6	35.5	0.6	38.3	27.3	164.9
	305-366	120-144	7.1	3.9	24.9	1.1	38.7	33.1	138.1
E-Treated Soil	0-30	0-12	6.3	2.8	113.9	0.6	19.4	30.6	111.1
	30-46	12-18	4.7	2.1	37.4	0.5	37.4	24.1	133.7
	46-61	18-24	5.6	2.7	37.8	1.6	37.8	29.7	135.1
	61-76	24-30	5.6	2.7	32.2	0.5	37.6	29.6	134.4
	76-91	30-36	5.2	2.5	43.7	0.5	43.7	35.5	136.6
	91-122	36-48	4.7	3.2	32.2	<0.5	43.0	32.0	80.6
	122-152	48-60	5.8	2.1	37.8	0.5	29.7	29.7	108.1
	152-183	60-72	<0.2	2.2	38.5	<0.5	35.7	27.5	137.4
	183-244	72-96	6.8	3.1	39.3	<0.5	36.5	30.9	140.4
	244-305	96-120	5.3	3.0	35.7	1.1	30.2	32.9	109.9
	305-366	120-144	4.7	3.3	29.9	1.6	35.3	29.9	108.7

Table 29. Trace Element Content of Soils[†]

Element	Total (mg/kg)
As	6 (0.1-40)
Cd	0.5 (0.1-0.7)
Cr	100 (5-3000)
Hg	0.03 (0.01-0.8)
Ni	40 (5-5000)
Pb	10 (2-2000)
V	100 (20-500)

[†] Kirkham (1979)

Organic Distribution

Comparative analyses of both total organic carbon and extractable oil and grease are given in Tables 30 through 34. An analysis of variance (ANOVA), using total organic carbon and oil and grease as duplicate measures of the same parameter, was employed to evaluate hydrocarbon levels between treated and untreated soil and hydrocarbon levels between depth intervals within sites. Hydrocarbon levels at Site A were significantly higher in the treated soil. An F test indicated the difference to be significant at better than a 1% level. The least significant difference (LSD) computed for Site A was used to compare oil and grease levels with depth in the treated site. This test suggested that oil and grease is retained within the surface 23 cm (9 in) of soil.

The ANOVA for Site B indicated that the greater hydrocarbon levels in the treated soil was significant at a 1% level. Variance with depth was significant down to 46 cm (2 ft) of soil. It should be noted that no attempt was made to split out the variability due to technique of measuring hydrocarbons from the error mean square, which reduces the sensitivity of testing differences between depths due to treatment.

Data evaluated for Site C do not reflect a statistical difference between untreated and treated soil hydrocarbon levels, although values decreased significantly with depth. Simple comparisons to the untreated soil are not possible due to contamination of the untreated soil selected to appreciable depths. However, in this coarse textured soil, the data suggest an attenuation of hydrocarbons within 1.8-2.4 m (6 to 8 ft) of the surface.

Hydrocarbons at Site D (Table 33) reflect the general trends found at Sites A and B, in that the treated soil had significantly higher hydrocarbons than the untreated soil, and the organics were attenuated within the surface 30 cm (1 ft) of soil.

Site E (Table 34) reflected no statistical differences due to treatment and correspondingly no differences with respect to depth. These data suggest that hydrocarbons loaded onto the soil have degraded without an appreciable migration of degradation products within the profile.

In three of the 5 cases studied, treated soils had significantly higher oil and grease contents to depths of 23 to 61 cm (9 to 24 in). In the case of Site C, a deep sand with a contaminated control for comparison, no significant increase in hydrocarbons was found by gravimetric analysis.

Table 30. Total Organic Carbon and Extractable Oil and Grease for Soils from Site A Given in Percentage.

Depth (cm)	Depth (in)	Untreated Soil		Treated Soil *	
		Total Organic Carbon	Oil and Grease	Total Organic Carbon	Oil and Grease
0-15	0-6	0.65	0.05	4.6	5.55 a
15-23	6-9	0.35	0.01	1.0	0.66 b
23-30	9-12	0.28	0.06	0.31	0.07 c
30-53	12-21	0.27	0.12	0.17	0.05 c
53-76	21-30	0.17	0.02	0.18	0.02 c
76-102	30-40	0.18	0.02	0.15	0.17 c
102-127	40-50	0.15	0.04	0.47	0.20 c
127-152	50-60	0.08	0.01	0.07	0.08 c

* Treated soil hydrocarbon level differs significantly from untreated soil

LSU at 0.05 = 0.28 Oil and grease values with different letter subscripts are significantly different at the 0.05 level.

Table 31. Total Organic Carbon and Extractable Oil and Grease for Soils from Site B Given in Percentage.

Depth (cm)	Depth (in)	Untreated Soil		Treated Soil *	
		Total Organic Carbon	Oil and Grease	Total Organic Carbon	Oil and Grease
0-15	0-6	4.1	0.24	6.0	3.49 a
15-30	6-12	1.5	0.05	6.5	3.98 b
30-46	12-18	0.58	0.16	6.5	1.63 c
46-61	18-24	0.37	0.06	< 0.01	0.71 d
61-76	24-30	0.37	0.03	1.10	0.38 d
76-91	30-36	0.27	0.04	1.6	0.62 d
91-122	36-48	0.37	0.05	0.35	0.08 d
122-152	48-60	0.25	0.04	0.60	0.18 d
152-183	60-72	0.19	0.04	0.12	0.13 d
183-244	72-96	< 0.01	0.04	0.24	0.07 d
244-305	96-120	0.47	0.04	< 0.01	0.06 d
305-366	120-144	0.20	0.01	0.46	0.06 d

* Treated soil hydrocarbon level differs significantly from untreated soil.

LSD at 0.05 = 0.86 Oil and grease values with different letter subscripts are significantly different at the 0.05 level.

Table 32. Total Organic Carbon and Extractable Oil and Grease for Soils from Site C Given in Percentage.

Depth (cm)	Depth (in)	Untreated Soil		Treated Soil*	
		Total Organic Carbon	Oil and Grease	Total Organic Carbon	Oil and Grease
0-15	0-6	4.0	2.71	5.5	7.86 a
15-30	6-12	2.3	0.16	1.3	2.60 b
30-46	12-18	1.9	0.96	0.75	0.59 c
46-61	18-24	2.2	1.49	1.2	0.79 c
61-76	24-30	1.6	2.12	0.79	0.49 cd
76-91	30-36	0.5	0.42	0.61	0.44 cd
91-122	36-48	< 0.01	0.04	0.58	0.06 d
122-152	48-60	< 0.01	0.11	0.53	0.49 cd
152-183	60-72	0.08	0.10	0.33	0.33 cd
183-244	72-96	< 0.01	0.01	0.06	0.02 d
244-305	96-120	< 0.01	0.01	< 0.01	0.08 d
305-366	120-144	0.66	0.01	< 0.01	0.05 d

* Treated soil hydrocarbon level did not differ significantly from untreated soil level.

LSD at 0.05 = 0.49 Oil and grease values with different letter subscripts are significantly different at the 0.05 level.

Table 33. Total Organic Carbon and Extractable Oil and Grease for Soils from Site D Given in Percentage.

Depth (cm)	Depth (in)	Untreated Soil		Treated Soil *	
		Total Organic Carbon	Oil and Grease	Total Organic Carbon	Oil and Grease
0-10	0-4	1.4	0.19	6.0	3.43 a
10-20	4-8	0.58	0.31	2.0	1.05 b
20-30	8-12	0.67	0.04	0.20	0.14 c
30-46	12-18	0.59	0.04	0.21	0.06 c
46-61	18-24	0.47	0.07	< 0.01	0.05 c
61-76	24-30	0.13	0.06	0.10	0.07 c
76-91	30-36	< 0.01	0.31	< 0.01	0.06 c
91-122	36-48	0.06	0.08	0.10	0.07 c
122-152	48-60	< 0.01	0.08	< 0.01	0.10 c
152-183	60-72	0.07	0.01	< 0.01	0.06 c
183-244	72-96	< 0.01	0.02	< 0.01	0.07 c
244-305	96-120	0.05	0.12	< 0.01	0.04 c
305-366	1 -144	< 0.01	0.28	0.19	0.07 c

* Treated soil hydrocarbon level differs significantly from untreated soil.

LSD at 0.05 = 0.36 Oil and grease values with different letter subscripts are significantly different at the 0.05 level.

Table 34. Total Organic Carbon and Extractable Oil and Grease for Soils from Site E Given in Percentage.

Depth (cm)	Depth (in)	Untreated Soil		Treated Soil *	
		Total Organic Carbon	Oil and Grease	Total Organic Carbon	Oil and Grease
0-30	0-12	4.0	0.10	3.3	0.46a
30-46	12-18	2.4	0.33	1.0	0.44a
46-61	18-24	1.9	0.43	0.86	0.12a
61-76	24-30	1.8	0.42	1.0	0.06a
76-91	30-36	2.0	0.11	0.51	0.40a
91-122	36-48	1.5	0.11	0.36	0.12a
122-152	48-60	0.5	0.07	0.20	0.03a
152-183	60-72	1.0	0.11	0.20	0.13a
183-244	72-96	0.21	0.38	0.07	0.06a
244-305	96-120	0.10	0.04	< 0.01	0.02a
305-366	120-144	0.10	0.31	0.14	0.04a

* Treated soil hydrocarbon level differs significantly from untreated soil

LSD at 0.05 = 0.28 Oil and grease values with different letter subscripts are significantly different at the 0.05 level.

Only one site had no increase in oil and grease due to treatment and no change with depth.

Gas Liquid Chromatographic Characterization

Detector Response: Gas liquid chromatographic (GLC) analyses in conjunction with column fractionation on silica gel was used to develop characteristic chromatograms in untreated and treated soil with respect to depth interval sampled.

A complex mixture of standards was injected to evaluate GC column conditions and detector response over a daily, weekly, and monthly time interval. Detector response, reported in integration units per mole carbon for the various hydrocarbons injected, averaged over time is presented in Table 35. Response in integration units per mole of carbon averaged over compounds and the standard deviation about the mean is also given. The column in line with detector 2 did not resolve n-docosane and phenyl carbazole into separate peaks. Thus, the value reported was computed relative to the total carbon between the two. These data suggested that the hydrocarbon response is relatively constant for a given instrument setting, when normalized to carbon injected setting. The standard deviation reflects variability over a 4 month time interval and innate differences between compounds, particularly xanthene. A detector response of 10,000 integration units require $100 \text{ ng C} \pm 18 \text{ ng C}$ for detector 1, and $80 \text{ ng C} \pm 10 \text{ ng C}$ for detector 2. Excluding xanthene does not numerically affect the standard deviation, such that 10,000 integration units correspond to $100 \text{ ng C} \pm 8.5 \text{ ng}$ for detector 1 and $80 \text{ ng C} \pm 4.5 \text{ ng C}$ for detector 2.

This discussion is not intended to imply the applicability of long term averages for quantification purposes - certainly daily standard injections are paramount for quality assurance - but is presented to describe the utility of the technique employed when dealing with complex unknowns. Standard addition entails multiple injections which are inordinantly time consuming for a long running temperature program required of most complex mixtures. Internal standards added to unknown mixtures may not necessarily reflect the class of compounds chromatographed, which parallel the inherent errors discussed previously and/or may co-elute with unknowns.

Column Chromatographic Fractionation: The standard (Table 35) fractionated on silica gel reflects the utility of this procedure for potentially reducing the complexity of

Table 35. Flame Ionization Detection Response to Hydrocarbons Reported as Integration Units Per Mole of C.

Peak No.	Compound	Detector Response	
		Detector No. 1	Detector No. 2
1	1,2-diphenylethane	1.26×10^{12}	1.39×10^{12}
2	Xanthene	0.89×10^{12}	0.92×10^{12}
3	Dibenzothiophene	1.25×10^{12}	1.54×10^{12}
4	Anthracene	1.16×10^{12}	1.37×10^{12}
5	n-Ethyl Carbazole	1.33×10^{12}	1.70×10^{12}
6	p-Terphenyl	1.24×10^{12}	1.50×10^{12}
7	Fluoranthene	1.32×10^{12}	1.62×10^{12}
8	n-docosane	1.16×10^{12}	1.60×10^{12}
9	n-Phenyl Carbazole	1.37×10^{12}	
10	Hexacosane	1.15×10^{12}	1.61×10^{12}
11	Cholestane	0.99×10^{12}	1.53×10^{12}
	Avg.	1.19×10^{12}	1.50×10^{12}
	Std. dev ($\delta \pm$)	0.18×10^{12}	0.18×10^{12}
	No observations	550	500

chromatograms for evaluating the fate of the various classes of compounds comprised in the waste added to soils (Figure 13). Saturates were cleanly separated in the standard mixture. Fraction 2 and Fraction 3 were combined due to an inconsistent separation of di- and tri- aromatic compounds from poly nuclear aromatic materials, as reported in the procedural paper (Warner, 1976). Fraction 4 contained the two carbozoles added in the standard mixture, although significant quantities of both were eluted in combined Fractions 2 and 3.

Soxhlet extracts of samples collected at the first three depth intervals were column fractionated on silica gel. Fractions 2 and 3 were combined in a similar manner as the standard prior to GLC analyses. Methanol was employed as a final rinse in an attempt to extract higher condensed polynuclear aromatics (e.g. asphaltenes) not eluted with the other solvents. No attempt was made to column fractionate Soxhlet extracts of samples collected at the lower depth due to the relatively low hydrocarbon levels and the potential for lowered concentrations for hydrocarbons recovered in multiple fractions. Thus, to improve the sensitivity level to hydrocarbons extracted from samples collected at the lower depths, chromatograms were developed for total extract following the removal of an aliquot for gravimetric analyses.

Molecular Weight and Carbon Number: A linear regression model was used to describe the relationship between retention time and molecular weight (MW) (Figure 14). Retention time (RT) corresponding to peak sensitivity for compounds used in the standard mixture and others including naphthalene, biphenyl, methyl heptadecanoate, 1, 3, 5-triphenyl benzene, triphenylethylene, tetraphenylethylene, and 9,9-bifluorene were found to increase linearly with increased molecular weight. Values (RT) averaged for multiple injections of known compounds of varying molecular weight gave a regression coefficient (r^2) of 0.84. These data suggest that hydrocarbons with less than 76 g/mole would be eluted with the solvent front at the same column and instrument conditions employed for the standards. A 20-min increase in retention time roughly corresponds to 5 carbons added in a chain configuration for saturates, or a benzene ring added for aromatics.

Similar results are reflected in the linear regression retention and carbon number (Figure 15). Again the fit of the model is reflected in the high regression coefficient value ($r^2 = 0.83$).

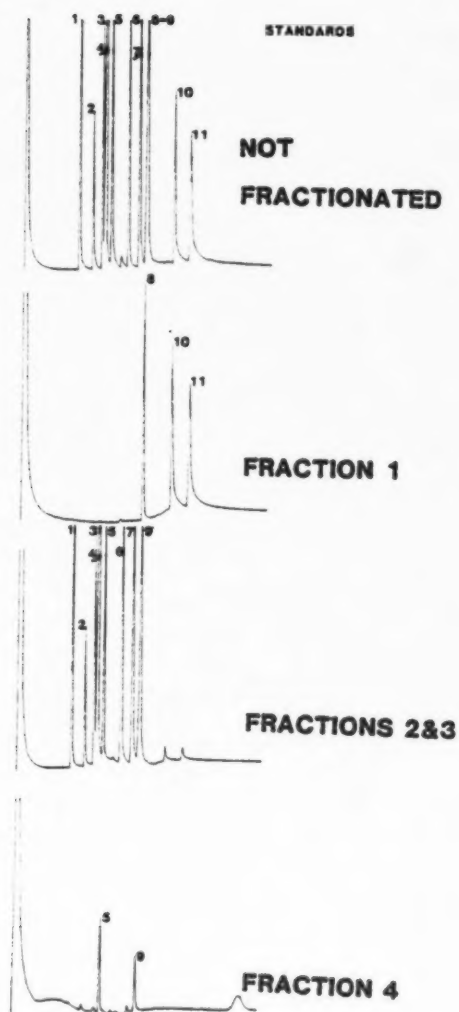


Figure 13. Chromatographs of standard compounds. Peak numbers refer to compounds listed in Table 35.

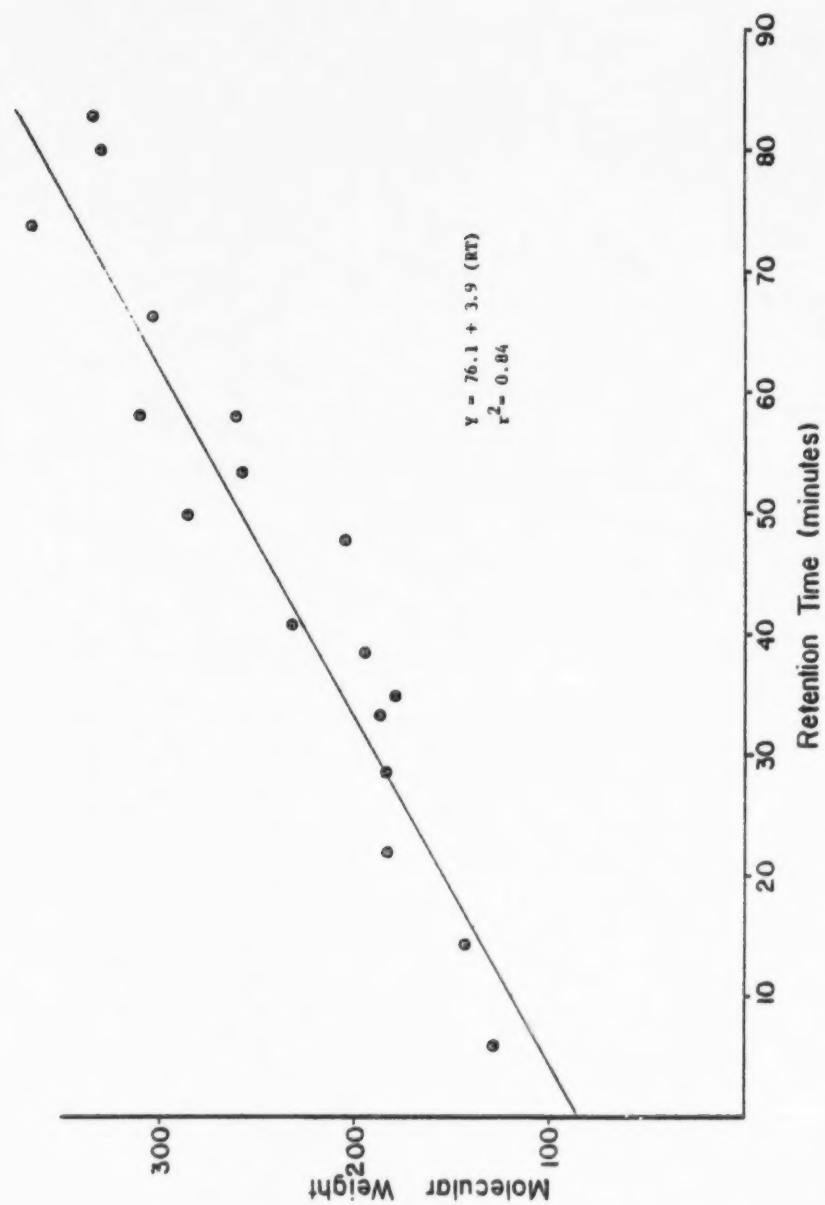


Figure 14. Relationship between retention time and molecular weight of known compounds.

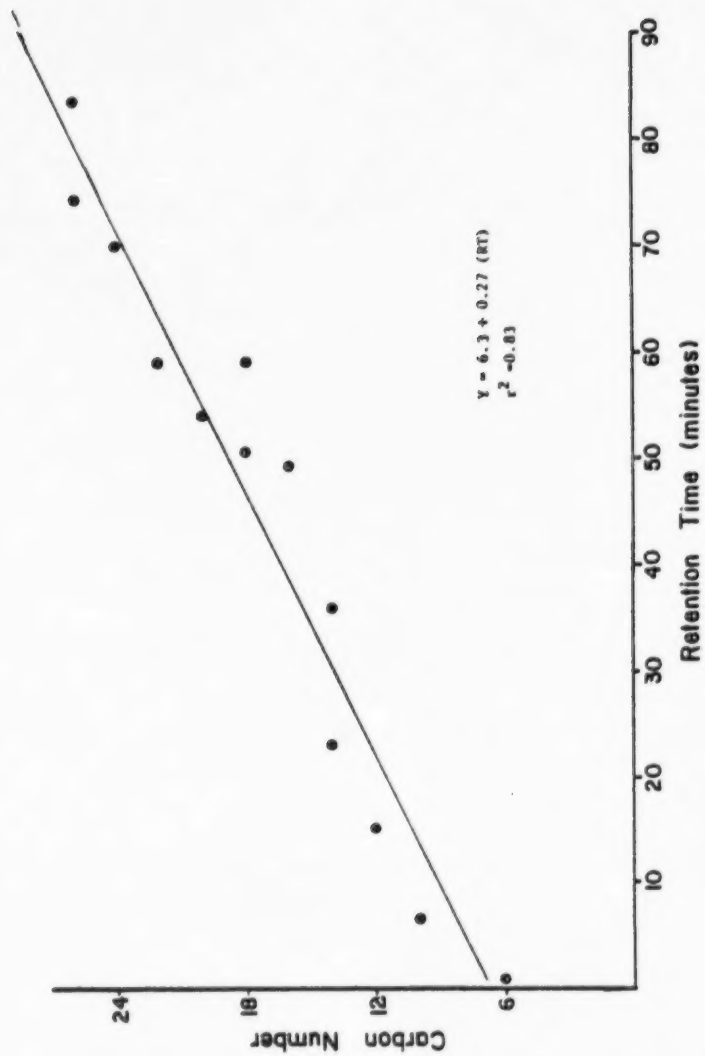


Figure 15. Relationship between retention time and carbon number of known compounds.

Hydrocarbon Distribution by Gas Liquid Chromatographic Analysis

Site A GLC Profiles: GLC comparative profiles for the various fractions over the first three depth intervals are given in Figures 16 and 17 for untreated and treated soil at Site A. A complex mixture of saturates eluted in Fraction 1, and polynuclear aromatics eluted in Fractions 2 and 3, dominate the hydrocarbons extracted from treated Site A. The decrease in hydrocarbons chromatographed with depth corresponds with the decreases observed for both total organic carbon and extracted oil and grease (Table 30).

Untreated soil was very low in extractable hydrocarbons with little detected by GLC in the upper profile. Chromatograms of extracted hydrocarbons of the lower levels in the profile which were not fractionated (Figure 18), begin to show some hydrocarbons at the 53 to 76 cm (21 to 30 in) depth interval in the untreated soil, with an even greater amount detected in the 76 to 102 cm (30 to 40 in) sample. Their occurrence is attributed to degradation products of natural soil humus. While the concentration of any one compound is relatively low, there is a noticeable accumulation of material at the 76 to 102 cm (30 to 40 in) depth interval suggesting a mechanism of illuviation and deposition in a base enriched zone. This is a natural phenomenon recently addressed in a paper by Holzhey et al. (1975). A similar trend was noted for the treated site, but with comparatively higher quantities chromatographed in the 76 to 102 cm (30 to 40 in) and 102 to 127 cm (40 to 50 in) depth intervals.

Fifteen months have elapsed since hydrocarbons were last applied at this site. The considerable quantity of material extracted and recovered in Fraction 1, and Fractions 2 and 3 may indicate a relatively slow degradation rate. This could be attributed to climatic factors. The area averages less than 38 cm (15 in) rainfall annually and only 159 frost free days. A slope of 4 to 7° at the site would tend to reduce the effective rainfall. Certain hydrocarbons applied to Site A remained in the upper 23 cm (9 in) for 15 months after application. Moisture deficiency may have retarded degradation and minimized the potential for mobility.

Site B GLC Profiles: The untreated soil chromatograms show few hydrocarbons resolved as peaks (Figure 19). Chromatograms of fractionated materials for treated Site B show a complex mixture dominated by saturates and aromatics (Figure 20).

Profiles developed for total extracts of samples taken

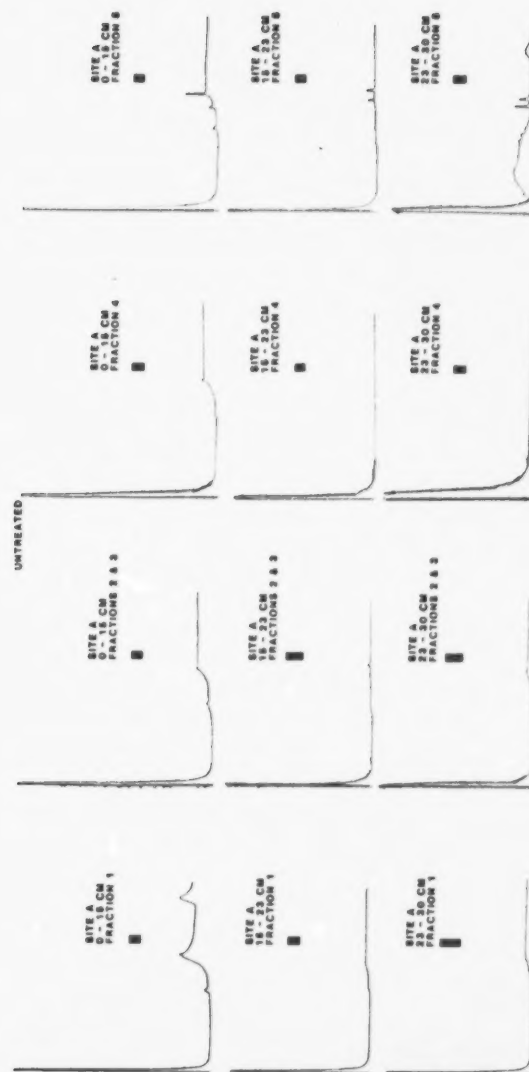


Figure 16. Chromatographs of fractionated soil extracts for the three surface depths at untreated Site A. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

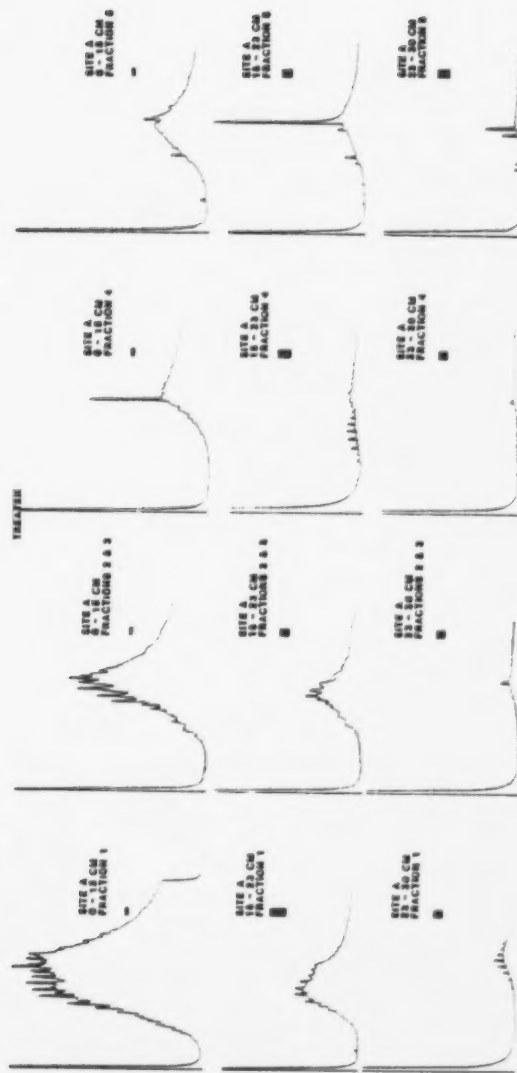


Figure 17. Chromatograms of fractionated soil extracts for the three surface depths at treated Site A. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

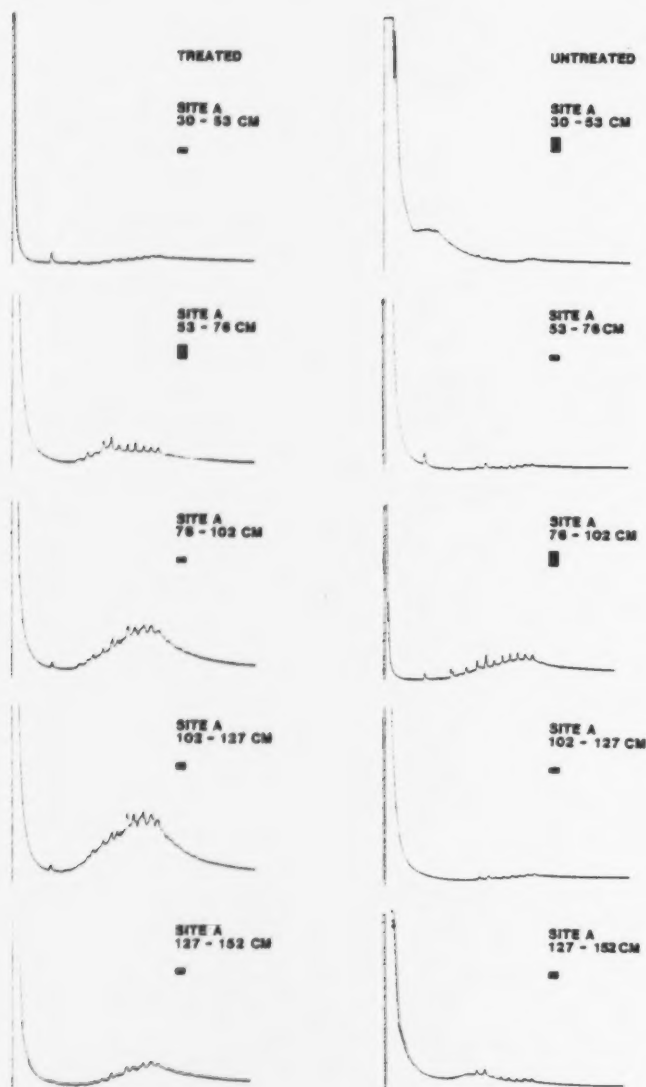


Figure 18. Chromatograms of the total extracts of soil below the top three sample locations at untreated and treated Site A. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

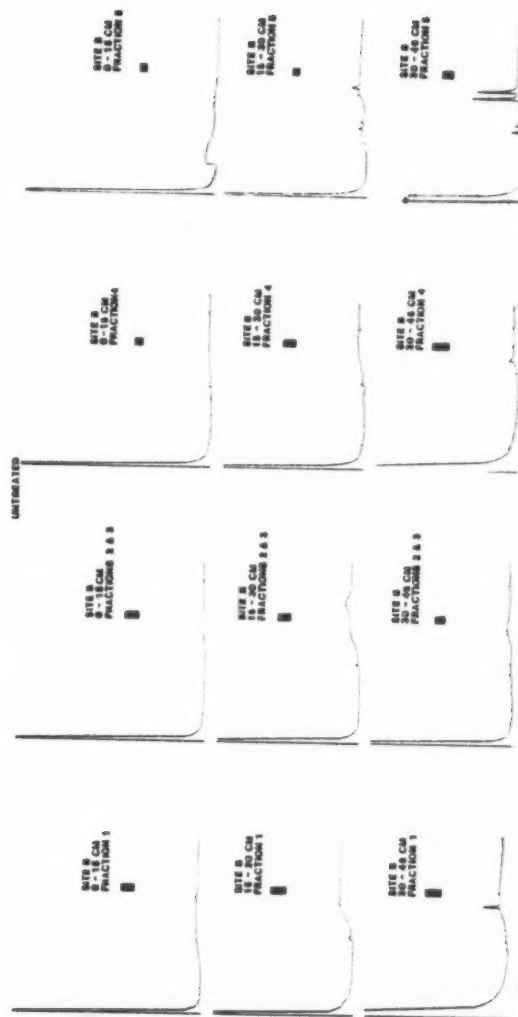


Figure 19. Chromatograms of fractionated soil extracts for the three surface depths at untreated Site B. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

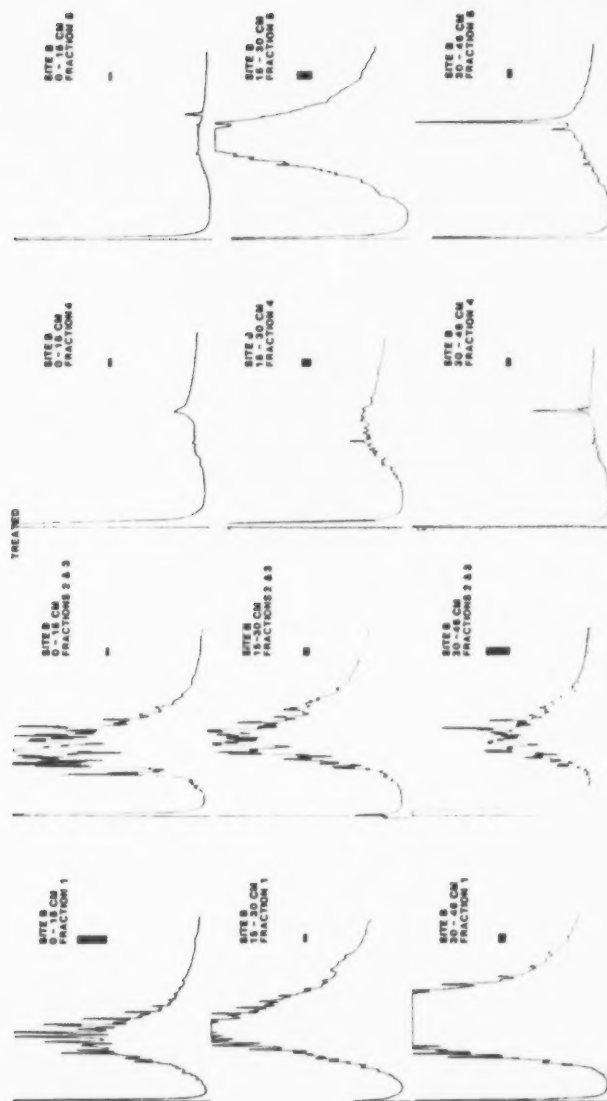


Figure 20. Chromatograms of fractionated soil extracts for the three surface depths at treated Site B. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

to 366 cm (12 ft) clearly show some migration of hydrocarbons out of the zone of incorporation, but also demonstrates retention of applied materials within the surface 91 cm (3 ft) of soil.

This site is a good example of how a textural discontinuity serves in the retention of hydrocarbons. The soil is a loam to sandy loam to approximately 61 cm (2 ft), underlain by 30 cm (1 ft) of coarser material. The coarser material for the treated site at 61 to 76 cm (24 to 30 in) (Table 2) retained fewer hydrocarbons as shown in both extracted values assayed gravimetrically (Table 30) and by GLC (Figures 21 a & b). Increased hydrocarbons in the next layer 76 to 91 cm (30 to 36 in) reflect an increased concentration of hydrocarbon backed up by slowed penetration into the zone below 91 to 122 cm (36 to 48 in) containing a much higher clay content.

Considerable hydrocarbons remained in the zone of incorporation although a year had passed since the last loading (Table 1). The data indicates the retention capacity of the soil for this waste stream, and a relatively low migration potential to deeper strata, afforded principally by a textural discontinuity.

Site C GLC Profiles: Characteristic profiles developed for the various fractions are compared for the first 3 sampling depths for untreated and treated soil at Site C (Figure 22 and 23, respectively). Profiles reflect the complexity of the waste materials applied just one month prior to sampling (Table 1), with the bulk of the organics being eluted in the first two fractions collected. The large cone shaped pattern is indicative of a complex matrix eluting from the GLC column unresolved into peaks. Although the materials chromatographed contain some saturates, the bulk is characteristically aromatic in nature, with molecular weights less than 300.

GLC analyses of samples taken to 366 cm (12 ft) show migration portions of the waste materials to a depth of 244 cm (8 ft) (Figure 24 a & b). Although the untreated soil shows similar materials to a depth of 91 cm (3 ft), the hydrocarbons are attributed to possible previous industrial use of the soil thought to be an untreated area. Chromatograms of materials fractionated for the upper 45 cm (18 in) of the supposedly untreated area are relatively clean with respect to differentiated peaks, but reflect a characteristic cone shape indicative of previous contamination.

The depth of penetration of near surface applied materials at this site is attributed to its very coarse

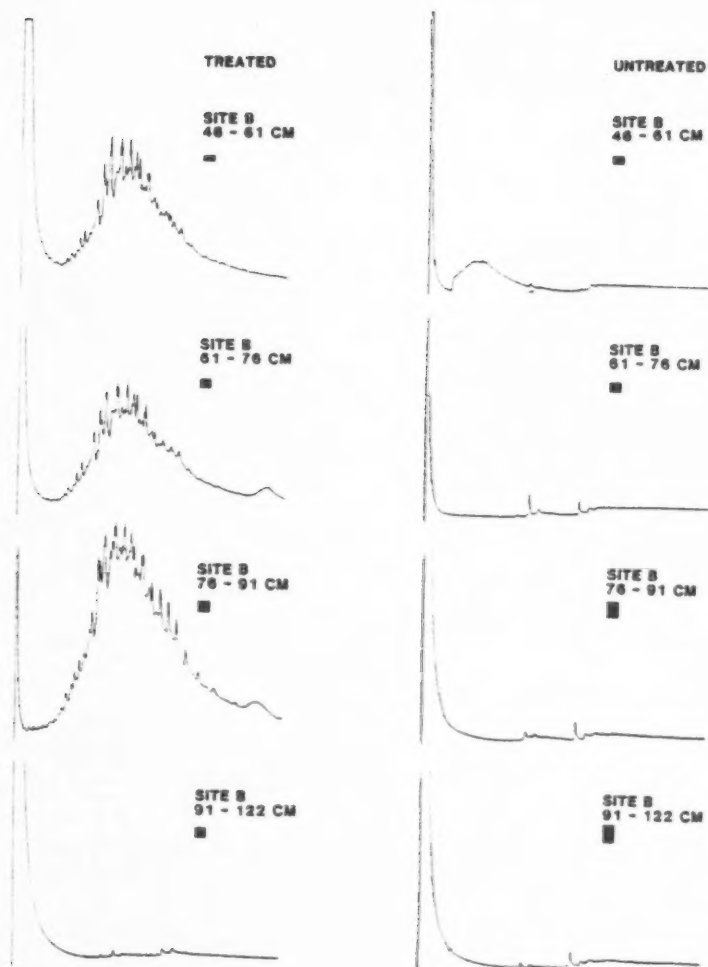


Figure 21a. Chromatograms of the total extracts of soil below the top three sample locations at untreated and treated Site B. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

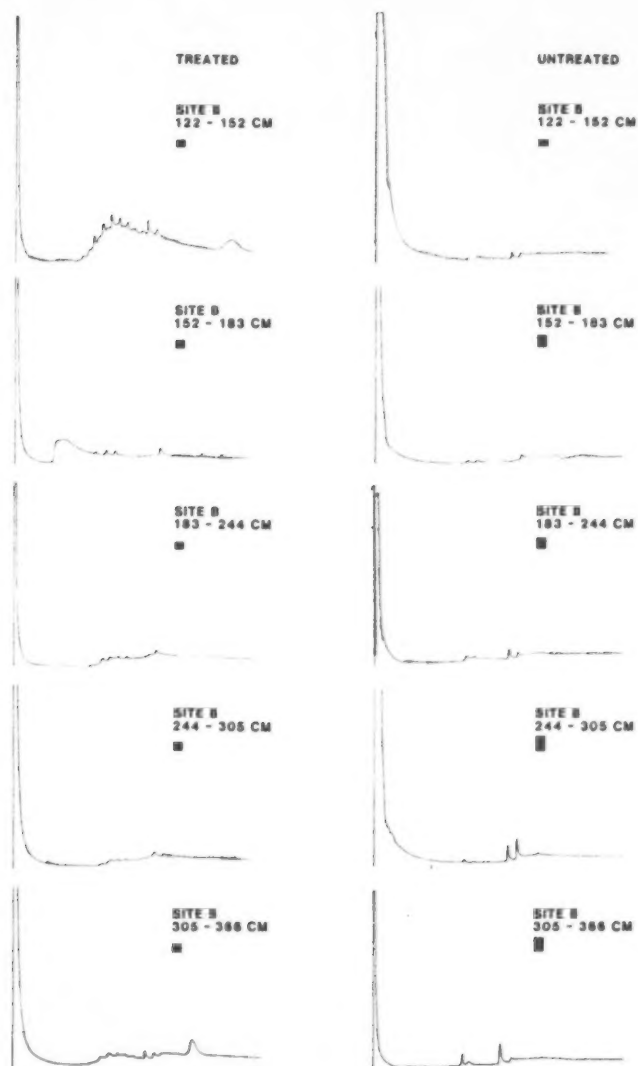


Table 21b. Chromatograms of the total extracts of soil below the top three sample locations at untreated and treated Site B. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

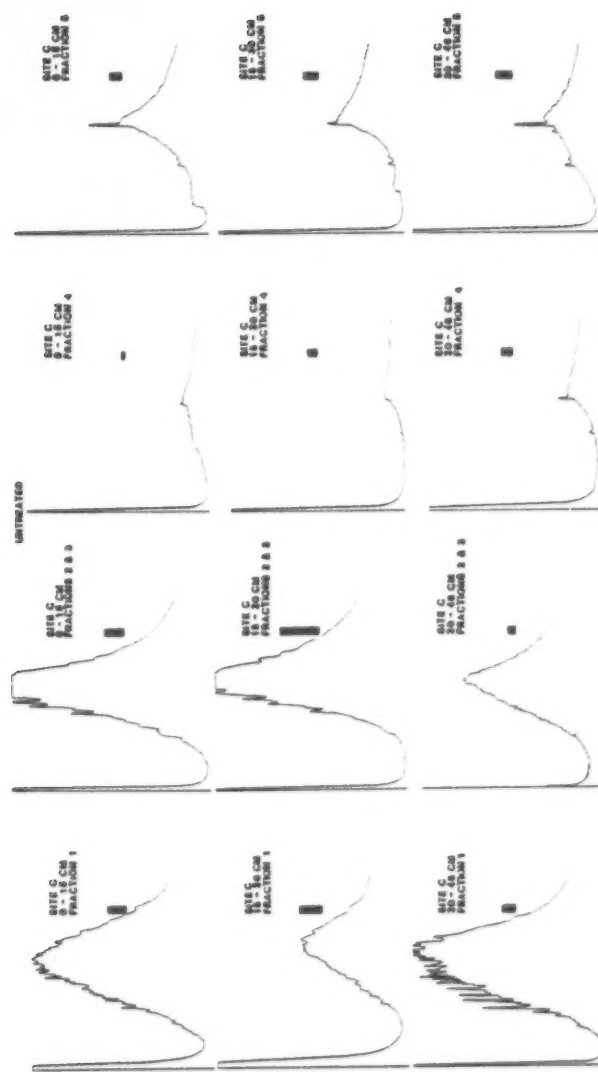


Figure 22. Chromatograms of fractionated soil extracts for the three surface depths at untreated Site C. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

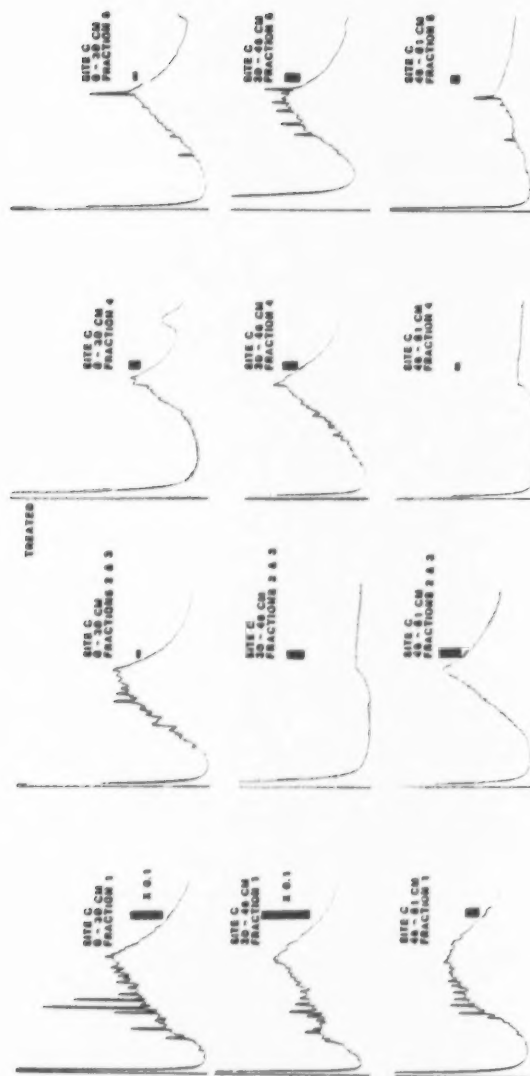


Figure 23. Chromatograms of fractionated soil extracts for the three surface depths at treated Site C. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

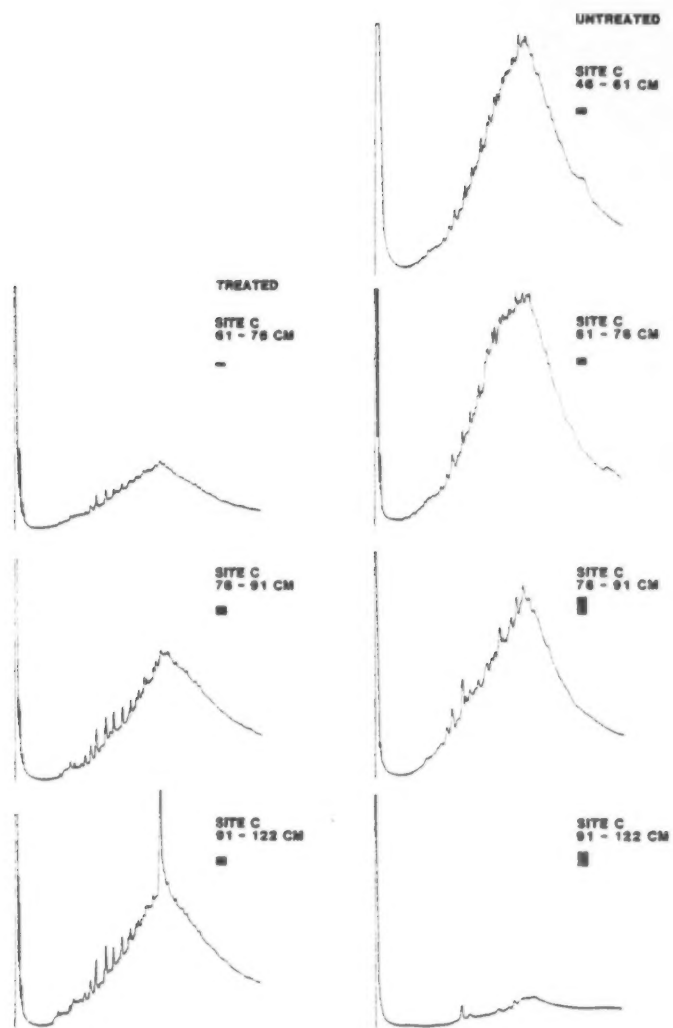


Figure 24a. Chromatograms of the total extracts of soil below the top three sample locations at untreated and treated Site C. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

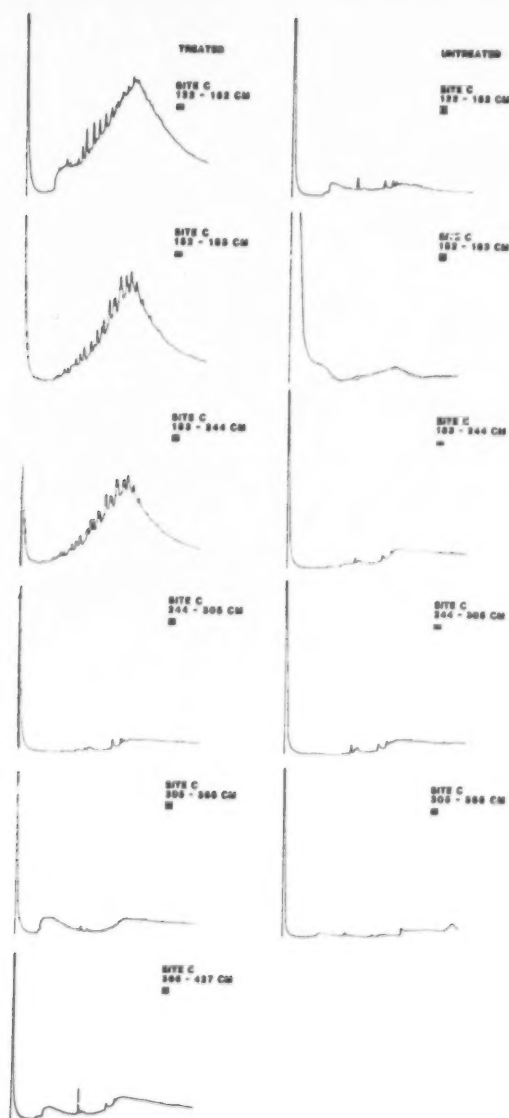


Figure 24b. Chromatograms of the total extracts of soil below the top three sample locations at untreated and treated Site C. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

texture. Degradation rates are expected to be much lower once materials penetrate the profile below the active surface solum.

Site D GLC Profiles: The GLC scan developed for the various fractions for the three surface layers of the untreated and treated soils at Site D are given in Figures 25 and 26. The area under the chromatograms correlates well with gravimetrically assayed oil and grease values (Table 33), and demonstrates that the waste applied to this site is retained within the zone of incorporation.

Chromatograms developed for total extracts of soil samples collected deeper in the profile reflect only the downward migration of materials normal to weathered products of soil humus (Figure 27a & b).

This site has been utilized since June 1976, and application was made in October, 1980, just 3 months prior to sampling (Table 1). The broad distribution of residual organics indicate that a wide spectrum of the organics applied remain in the zone of incorporation. Changes in this distribution would be expected as degradation proceeds, particularly in the winter months.

Site E GLC Profiles: GLC profiles developed for the various fractions for the first 3 sampling depths for untreated and treated soil at Site E are given in Figures 28 and 29. The extractable organics are dominated by saturates and light end (low molecular weight) aromatics. While appreciable hydrocarbons were extracted from untreated soil and assayed gravimetrically, most were not amenable to GLC analysis, making it impossible to compare characteristic profiles between sites and depths within sites.

The surface profile (Figure 29) of the treated site demonstrates degradation within 4 months following the last application (Table 1). Profiles also suggest migration to successive depths but with considerable attenuation within the top 61 cm (2 ft) of soil. While low in concentration, hydrocarbons extracted from treated soil at lower depths reflect the characteristic profiles of the upper zones (Figure 30 a & b), and suggest some penetration to the 91 to 122 cm (36 to 48 in) depth interval.

There are two plausible explanations for material movement at this site; one based on waste material loading, the other on the type clay to which it was applied. It is possible that the waste material applied has a low affinity for the clay surface and moves through the cracks in this soil to greater depths. While a heavy clay would no doubt

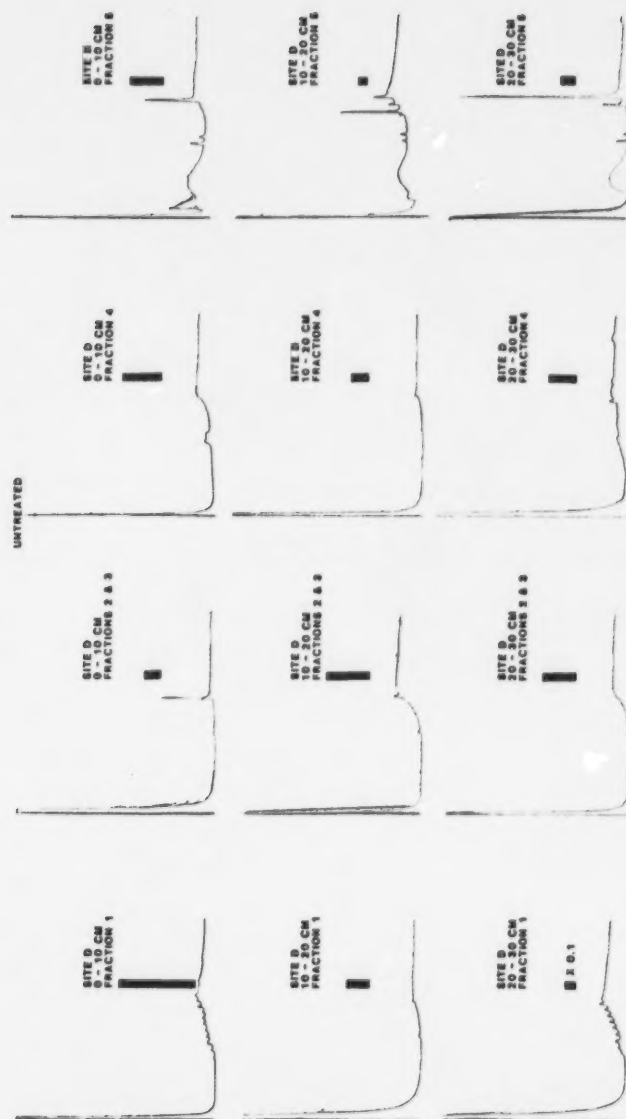


Figure 25. Chromatograms of fractionated soil extracts for the three surface depths at untreated Site D. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

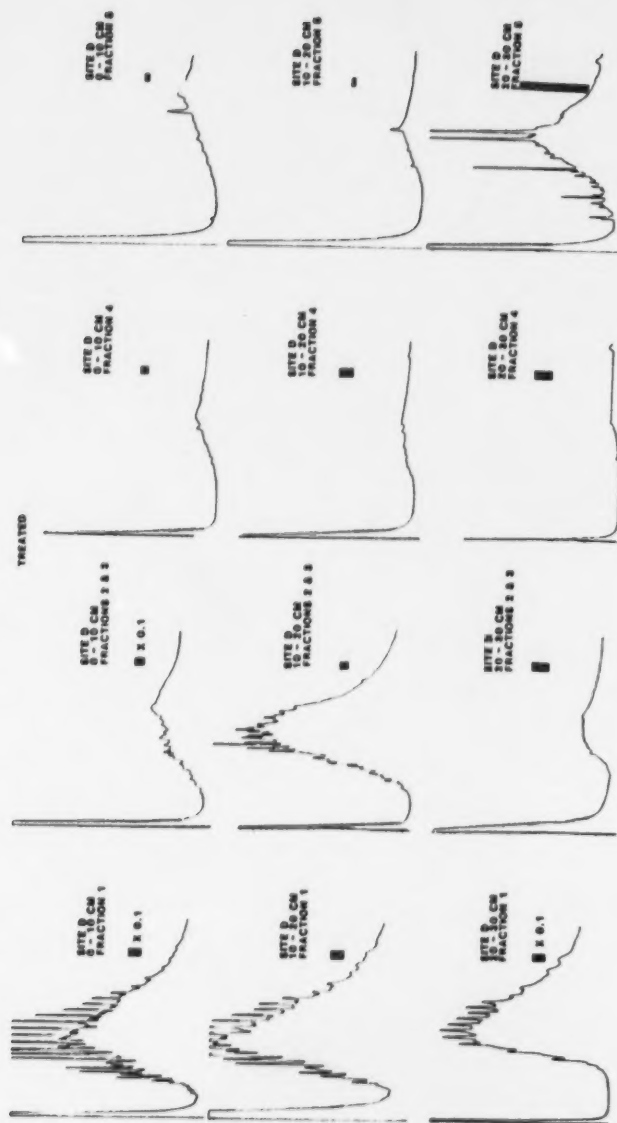


Figure 26. Chromatograms of fractionated soil extracts for the three surface depths at treated Site D. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

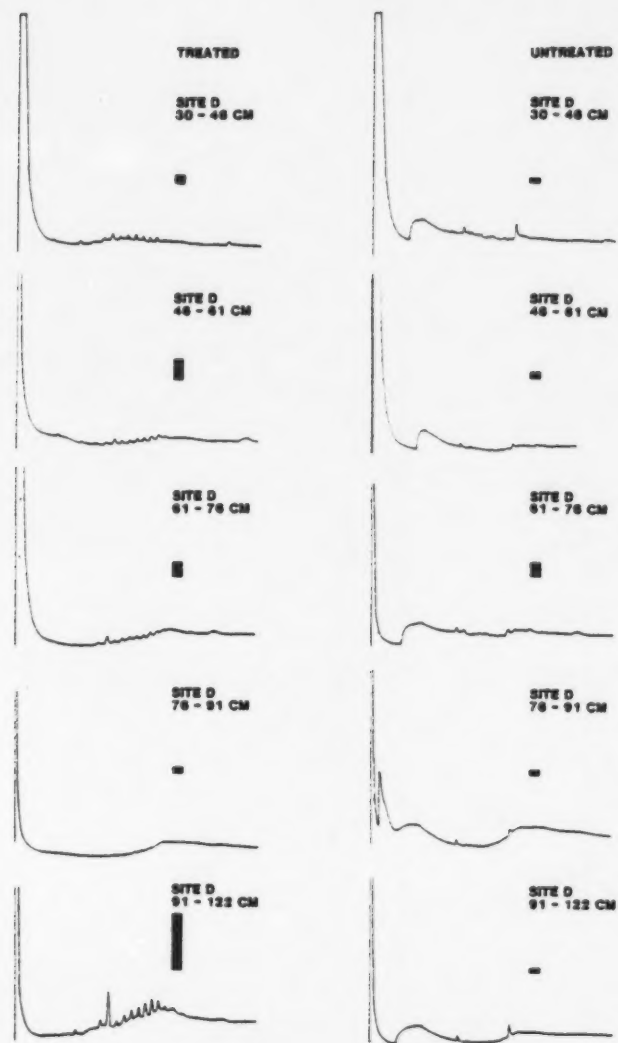


Figure 27a. Chromatograms of the total extracts of soil below the top three sample locations at untreated and treated Site D. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

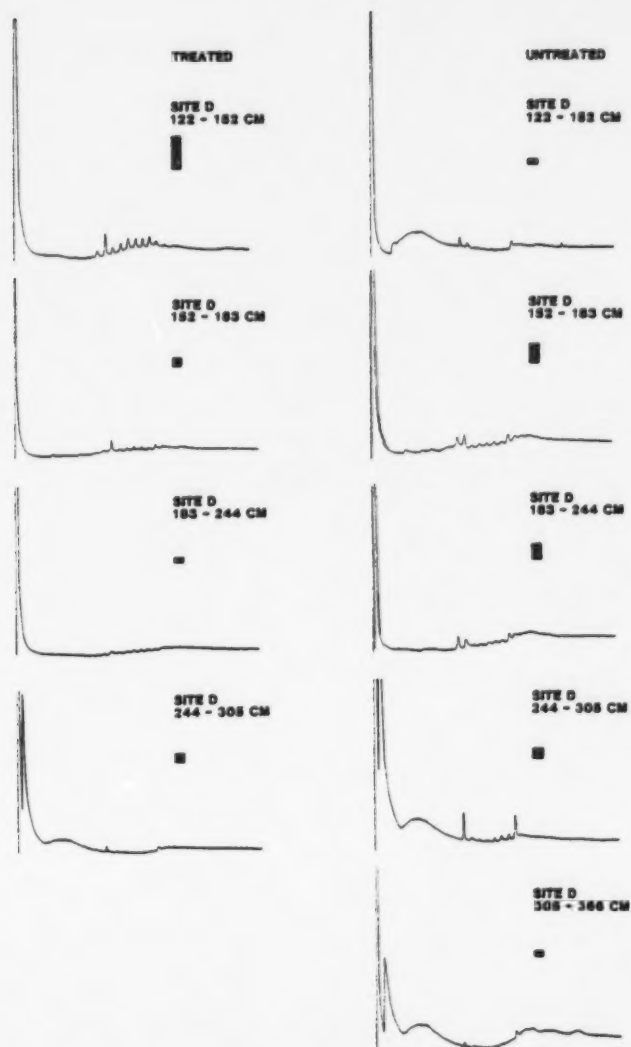


Figure 27b. Chromatograms of the total extracts of soil below the top three sample locations at untreated and treated Site D. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

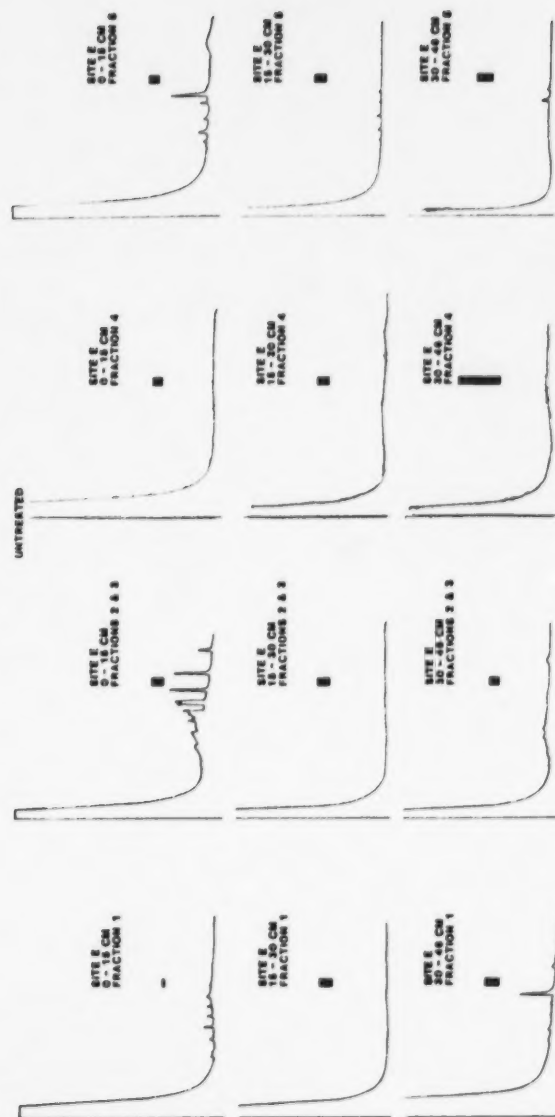


Figure 28. Chromatograms of fractionated soil extracts for the three surface depths at untreated Site E. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

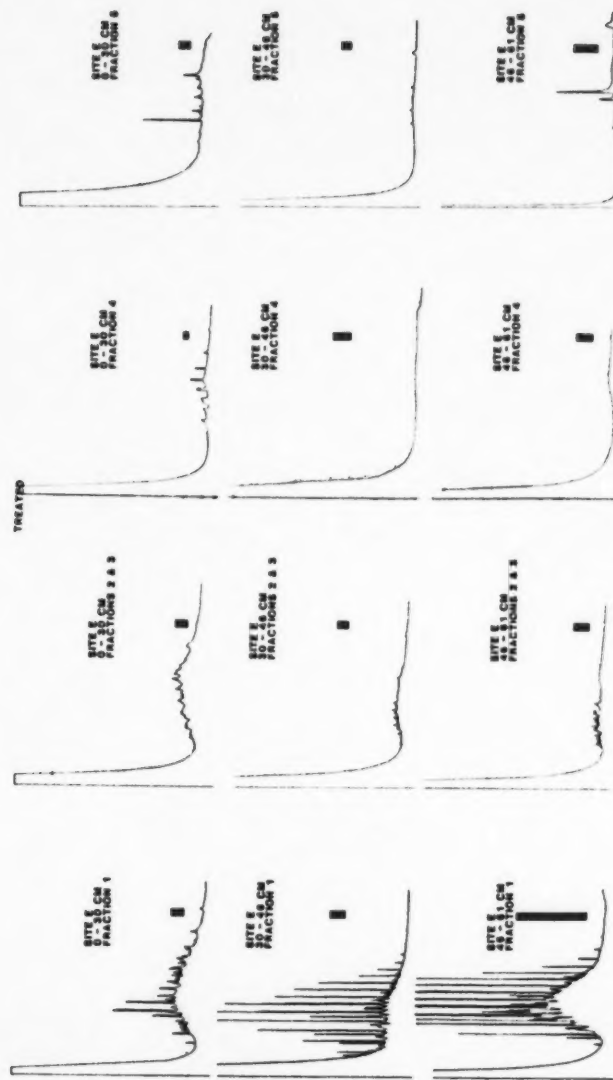


Figure 29. Chromatograms of fractionated soil extracts for the three surface depths at treated site E. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

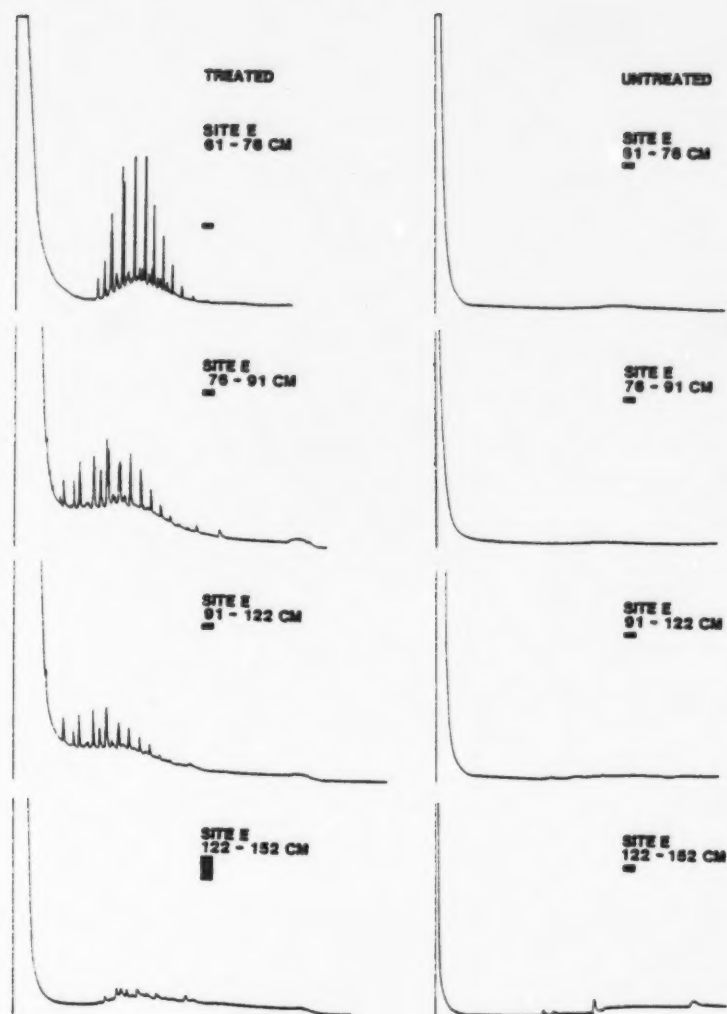


Figure 30a. Chromatograms of the total extracts of soil below the top three sample locations at untreated and treated Site E. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

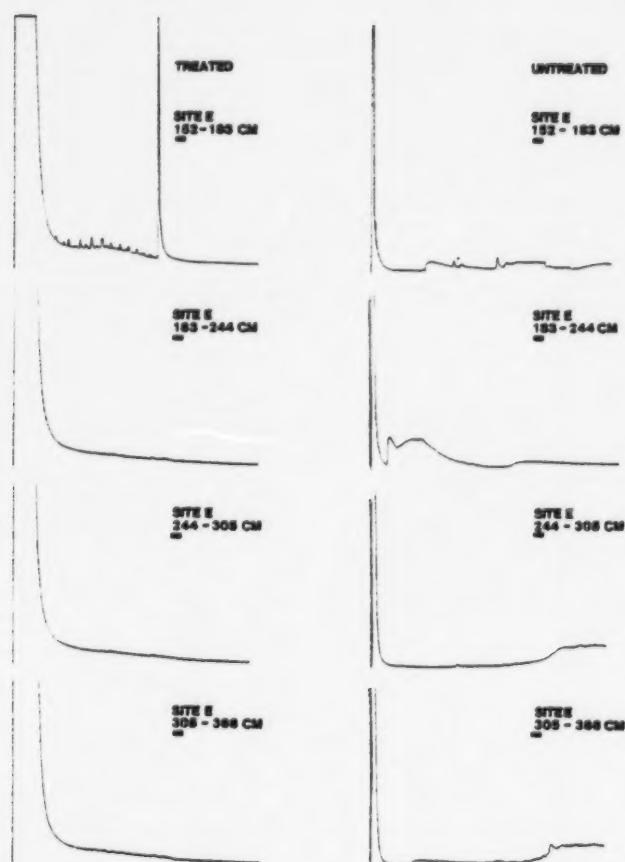


Figure 30b. Chromatograms of the total extracts of soil below the top three sample location at untreated and treated Site E. Rectangles in each legend represent the area equivalent to 10 n moles C per gram oven dry soil.

induce a more tortuous path (chromatographic effect), movement out of the active surface solum, especially at too high an application rate, could exceed the potential degradation rate. The other mechanism is one induced by the fact that receiving soil is a vertisol characterized by its shrink-swell properties that result in cracks and fissures developed during a dry cycle. This results in a churning of the soil whereby surface materials fall into cracks, distributing the surface applied materials throughout the profile. This mechanism is reflected in the carbon profiles shown in Table 34. Ironically the rapid degradation rate at this site and relatively high rainfall which usually enhances mobility could serve to reduce potential mobility of this waste stream.

High Performance Liquid Chromatography (HPLC)

Surface horizons for all treated sites, and subsurface samples showing significant hydrocarbons (by GLC-flame ionization detection) were analyzed by HPLC. A characteristic profile developed for the standard mixture is given in Figure 31. To aid in the detection of phenolic derivatives, analyses were made by injection of a methanolic extract of the sample. Extracts were generated by high speed blending of sufficient sample to provide a detection limit to 1 ppm phenol based on the integrated area of the standard.

Comparative retention time and area ratio analyses show only two surface samples and one subsurface sample to possibly contain phenolic materials. These being the immediate surface samples collected at treated Site A (Figure 32) and treated Site E (Figure 33), and the 76 to 91 cm (30 to 36 in) depth interval sampled at treated Site B (Figure 34). While several phenolic derivatives fit the retention time criteria, only pentachlorophenol passed the area ratio test for the surface samples at treated Site A and E. Although, no attempt was made to positively identify the material as pentachlorophenol, sample extracts were screened for halogenated hydrocarbons using an electron capture Ni^{63} detector fitted to Tracor Model 550 gas chromatograph equipped with a 3% OV-1 packed column. Based on the detector's response to lindane, aldrin, dieldrin, heptachlor, and arochlor 1254, no halogenated hydrocarbons were detected in quantities exceeding 1 ppm, which strongly suggests that material detected in the phenolic screening as potentially pentachlorophenol was something other than a chlorinated hydrocarbon.

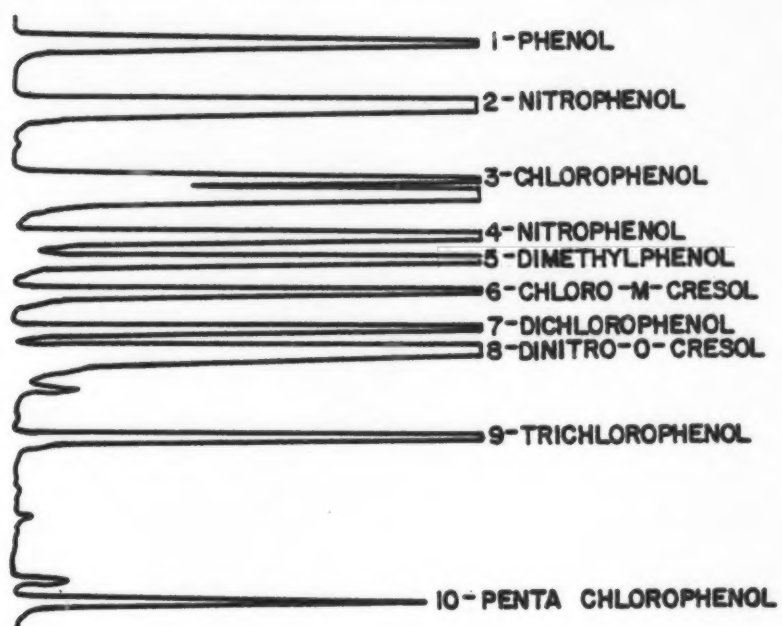


Figure 31. HPLC scan of standard samples.

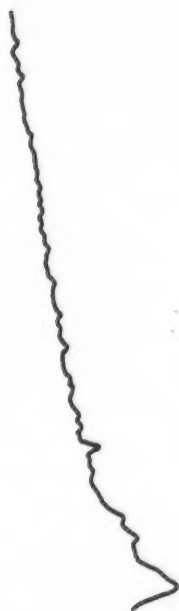


Figure 32. HPLC scan of the 0-15 cm of the extract from the treated site at Location A.



Figure 33. HPLC scan of the 0-30 cm of the extract from the treated site at Location E.



Figure 34. HPLC scan of the 76-91 cm of the extract from the treated site at Location B.

Phenol was the only material to pass a ratio test for the subsurface sample collected at treated Site B. Since the concentration is low (~ 1 ppm phenol), and no phenol was detected in the surface horizons, this result was considered to be of little significance, and no attempt at positive identification was made.

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APPENDIX A
Climatological Data for the Sites Sampled

Appendix Ia . Average Precipitation in Inches by Month for all Locations.

Site	Time Period	Months												Annual
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
A	1940-1979	0.79	0.64	1.02	1.62	2.14	2.46	0.92	0.93	1.34	1.12	0.77	0.72	14.47
B	1955-1979	4.73	3.46	3.03	2.65	2.10	1.70	1.31	1.55	2.27	3.63	4.46	5.15	36.04
C	1940-1979	3.09	3.07	2.58	1.06	0.32	0.06	0.01	0.05	0.23	0.50	1.35	2.60	14.92
D	1940-1979	1.51	1.52	1.36	1.91	3.13	2.88	1.93	2.34	4.82	2.59	1.81	1.60	27.48
E	1940-1979	3.75	3.07	2.63	3.58	4.68	4.43	4.19	4.16	4.81	3.69	4.01	4.18	47.18

Appendix 1b . Average Temperature by Month for all Locations.

Site	Time Period	Months												Annual
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
A	1940-1979	21.8	27.1	33.8	45.2	55.2	63.5	72.6	70.7	59.9	49.6	35.3	27.8	46.9
B	1955-1979	37.2	41.2	43.4	47.8	54.1	59.0	62.5	61.9	57.3	50.2	42.8	40.2	49.8
C	1940-1979	55.9	57.0	58.5	60.8	63.4	67.2	71.5	72.3	70.8	66.6	62.2	57.6	63.6
D	1940-1979	56.3	59.1	65.0	71.5	76.8	81.0	83.3	83.4	80.6	71.9	64.9	58.4	71.2
E	1940-1979	49.7	53.8	61.5	67.8	73.9	79.8	82.4	81.7	77.6	69.2	59.2	54.2	67.6

Appendix 1c . Average Evaporation by Month for all Locations.

Site	Time Period	Location												Annual Total
		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
A	1955-1980	-	-	-	4.03	6.39	7.63	9.16	8.20	5.05	-	-	-	40.46
B	1955-1979	0.02	0.06	0.43	1.46	4.15	5.20	6.45	5.30	3.25	0.69	0.14	0.02	27.17
C	1959-1979	2.89	4.79	4.86	6.11	7.16	7.59	8.53	8.26	6.74	5.15	3.60	2.75	68.63
D	1955-1979	3.19	4.22	5.04	5.83	6.84	7.80	7.91	7.54	5.84	5.06	3.91	3.17	66.35
E	1955-1979	2.95	3.37	4.83	5.64	7.12	7.72	7.74	7.12	5.89	5.28	3.86	2.72	64.24

APPENDIX B

Site Description

Sampling Site: A. Sampling Date: November 24, 1980.

I. Topography

A. General Description: This site is composed of two experimental plots approximately one acre each within a larger enclosure. The terrain is a rolling hills type, and the elevation in this area ranges from 823 to 1,189 m (2,700 to 3,900 ft). The native vegetation of area consists mainly of western wheatgrass (Agropyron smithii), green needlegrass (Stipa viridula), and sagebrush (Arternisia filifolia). There was no vegetation on site.

B. Slope: The area consists of a 4 to 7 percent slope.

I. Soil

A. General Description (name): The soil is a Kyle series. This series consists of a silty clay, well-drained, nearly level, gently sloping and fine textured soil. The 4 to 7% slope Kyle silty clay occurs on fans, foot slopes, and uplands. The soil is mainly used for dry farming and for range.

B. Depth and Acidity: Kyle silty clay is a moderately to strongly alkaline soil which occurs to a depth of 152 cm (60 in). The shale parent material occurring at a depth greater than 152 cm (60 in) is a clay.

C. Profile (color, structure):

Ap - 0 to 23 cm (0 - 9 in), grayish-brown (2.5Y 5/2) silty clay, dark grayish-brown (2.5Y 4/2) when moist; moderate, fine granular structure in upper part to moderate, fine and very fine blocky in lower part; extremely hard when dry, firm when moist, and sticky and plastic when wet (surface 8 cm (3 in) was frozen but dry at the time of the sampling); calcareous; pH 7.7; abrupt boundary.

C₁ - 23 to 61 cm (9 to 24 in), grayish-brown (2.5Y 5/2) clay, dark grayish-brown (2.5Y 4/2) when moist; moderate, fine and very fine, blocky in upper part; few medium-sized pressure surfaces in lower part; extremely hard when dry, very firm when moist, sticky and very plastic when wet, calcareous; pH 7.8; gradual boundary.

C₂ - 61 to 152 cm (24 to 60 in), light brownish-gray (2.5Y 6/2) clay, dark grayish-brown (2.5Y 4/2) when moist; massive; a few lenses of silty clay loam 8 cm (3 in) thick; extremely hard when dry, very firm when moist, very sticky and plastic when wet; calcareous; pH 8.2.

The Kyle silty clay (4-7% slope) differs from the typic in that it has less clay in all horizons.

III. Climate:

- A. Rainfall: The annual precipitation is 33 cm (13 in).
- B. Pan Evaporation: The average warm season evaporation is 107.1 cm (42.18 in).
- C. Seasonal Temperature: The mean annual temperature is 46°F.

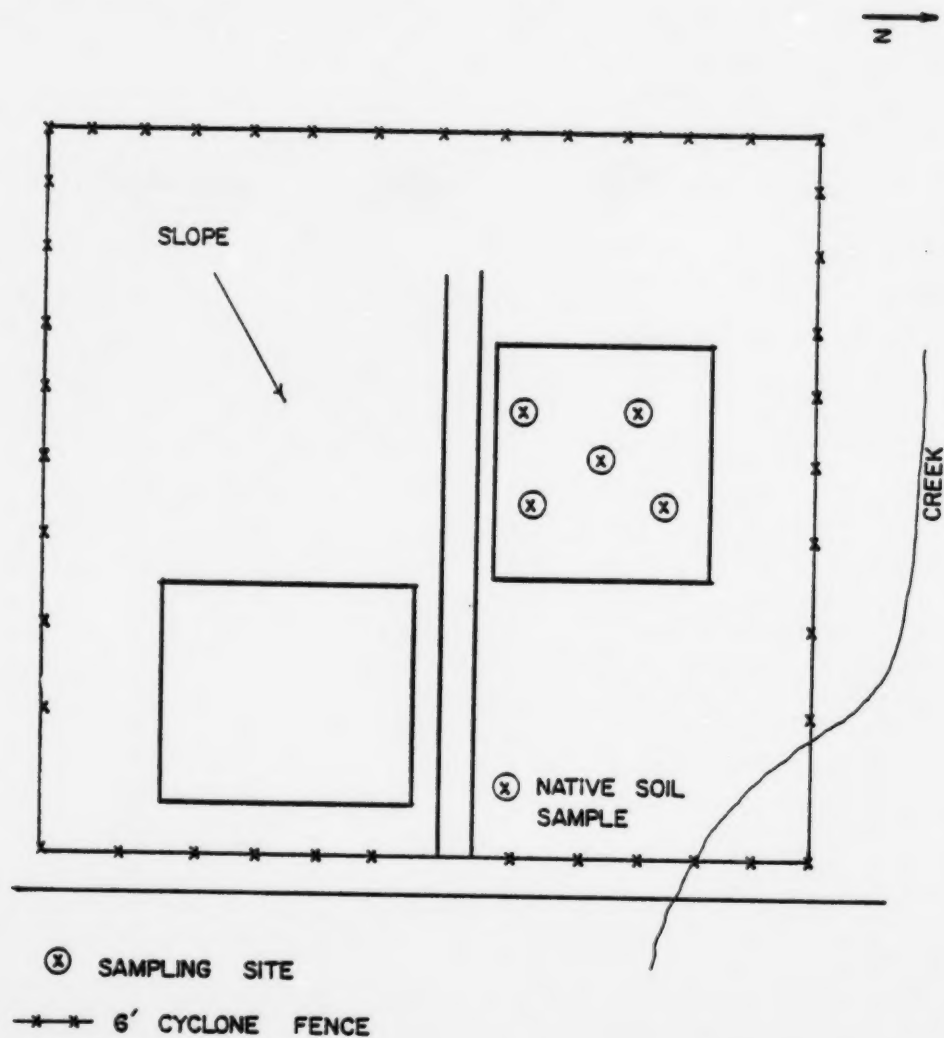


Figure B-1. Land treatment sample area for Site A.

Sampling Site: B. Sampling Date: July 1-2, 1981.

I. Topography

- A. General Description: The facility is roughly 6 acres in size, is located ca 1.2 km (three quarters of a mile) from the coast, and the elevation of the area is 152 meters (500 ft) above sea level. The terrain is composed of upland and terrace depressions, and the intrazonal soils have developed mainly under conditions of excessive moisture. The typical legumes, grasses and trees of the area are as follows: alsike clover (Trifolium hybridum L.), white clover (Trifolium repens L.), Italian ryegrass (Lolium multiflorum Lam.), Kentucky bluegrass (Poa pratensis L.), Douglas fir (Pseudotsuga menziesii) and cedar (Juniperus virginiana Linn.). There was no vegetation on site.
- B. Slope: The sample site consists of a 1 to 2 percent slope.

II. Soil

- A. General Description (name): The four land treatment samples were found to be a Norma silty clay loam - Cagey silt loam, undulating complex. The Norma and Cagey soils are blended in a transitional zone at the land treatment site. The control sample was taken at a location typical of the Norma silty clay loam series.

The Norma soils are formed from thin mantles of gravel or sand which overlie heavy clay and are probably modified by loesslike materials. The Cagey soils have developed from loesslike mantled gravelly drift over a clay till.

Both Norma and Cagey soils have a layer of gravelly sand occurring at approximately 46 to 51 cm (18 to 20 in) in depth. Penetration of this layer in the soils at the land treatment sampling site proved to be extremely difficult, and the method of sampling was modified in order to circumvent the problem. A tube was used to sample the first 46 cm (18 in), and then an auger was used to penetrate the tight gravelly layer. On one core sample, the auger was used exclusively after repeated efforts to penetrate with the tube failed.

Probably two-thirds of the Norma silty clay loam and Cagey silt loam, undulating have been cleared for crops and pasture. The high moisture content and slow drainage of the soils are more favorable for hay, pasture, and small grains.

- B. Depth and Acidity: The Norma silty clay loam soil occurs to a depth of 147 to 198 cm (58 to 78 in) and varies in acidity from slightly acid to a depth of 144 cm (58 in) and neutral or slightly alkaline from 147 to 198 cm (58 to 78 in).

The Cagey silt loam, undulating soil occurs to a depth of 122+ cm (48+ in) and is medium acid to a depth of 122 cm (48 in) and neutral or mildly alkaline from 122+ cm (48+ in).

- C. Profile (color, structure):

Norma silty clay loam

- 0 to 13 cm (0 to 5 in), dark brownish-gray granular silty acid silty clay loam having a high content of organic matter; nearly black when wet; 10 to 15 cm (4 to 6 in) thick.
- 13 to 46 cm (5 to 18 in), light brownish-gray clay loam having a 1.27 cm (1/2 in) blocky structure; dark brown when wet; 25 to 38 cm (10 to 15 in) thick.
- 46 to 147 cm (18 to 58 in) light yellowish-brown slightly acid somewhat compact but open and porous iron-stained gravelly sand; 91 to 122 cm (36 to 48 in) thick.
- 147 to 198 cm (58 to 78 in), light olive-gray dense clay till; shows angular fractures and is embedded with gravel, stones and boulders; varies considerably in thickness; neutral or slightly alkaline; in some areas along the coast contains marine shells.

Cagey silt loam, undulating

- 0 to 36 cm (0 to 14 in), moderately dark brown or rich-brown floury mellow very fine granular silt loam; contains fine shot pellets; layer is 10 to 36 cm (4 to 14 in) thick; medium acid.

36 to 51 cm (14 to 20 in), lighter medium-brown subsurface layer of floury, silt loam; contains more shot and is more compact than layer above; 10 to 25 cm (4 to 10 in) thick; medium acid; abruptly underlain by next layer.

51 to 122 cm (20 to 48 in), grayish-brown or grayish-yellow highly iron-stained porous gravelly sands; medium acid; material slightly coated with clay; 51 to 76 cm (20 to 30 in) thick.

122+ cm (48+ in), steel-gray or bluish-gray rusty or iron-stained dense clay till fractured into massive blocks; fracture planes darkened by brown colloidal matter; neutral or mildly alkaline.

III. Climate:

- A. Rainfall: The annual precipitation is 117 cm (46.2 in).
- B. Pan Evaporation: The average warm season evaporation is 65.5 cm (25.8 in).
- C. Seasonal Temperature: The mean annual temperature is 49.2°F.

LAND TREATMENT SAMPLE AREA

●-CONTROL

X-LAND TREATMENT
SAMPLES

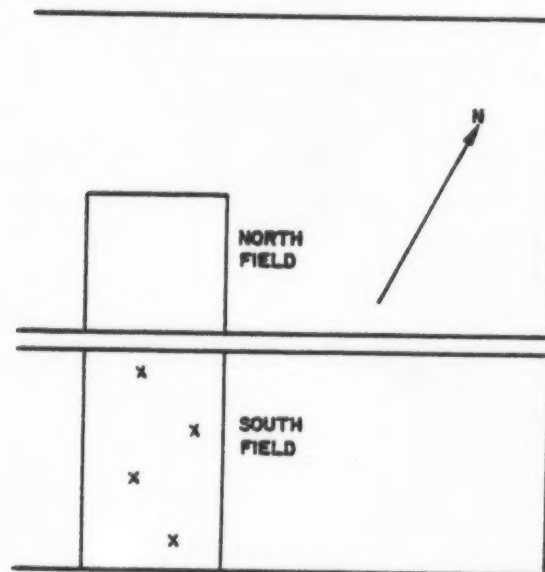


Figure B-2. Land treatment sample area for Site B.

Sampling Site: C. Sampling Date: December 8-11, 1980.

I. Topography

- A. General Description: The land treatment covers approximately 2.4 hectares (6 acres), and the site is surrounded by approximately a 7.62 m (25 ft) concrete wall. The site is located in a lagoon area with an elevation of approximately 24.4 m (80 ft). The vegetation is typical of species occurring only on extremely disturbed areas.
- B. Slope: The area consists of a 0.5% slope.

II. Soil

- A. General Description : The soil was originally classified as Oakley fine sand; however, this series was discontinued around 1962. The area of the refinery has not been reclassified in the interim. The Area Soil Scientist visited the treatment site, and a copy of the results of his analysis indicated that he would call the soil a Typic Xeropsamment mixed thermic. The treatment area is approximately 1.4 miles from the coast.

III. Climate:

- A. Rainfall: The average annual rainfall is 37.9 cm (14.92 in) for 1940-1979.
- B. Pan Evaporation: The average annual evaporation is 170 cm (66.97 in) for 20 years.
- C. Temperature: The average annual temperature is 63.6 degrees for 1940-1979.

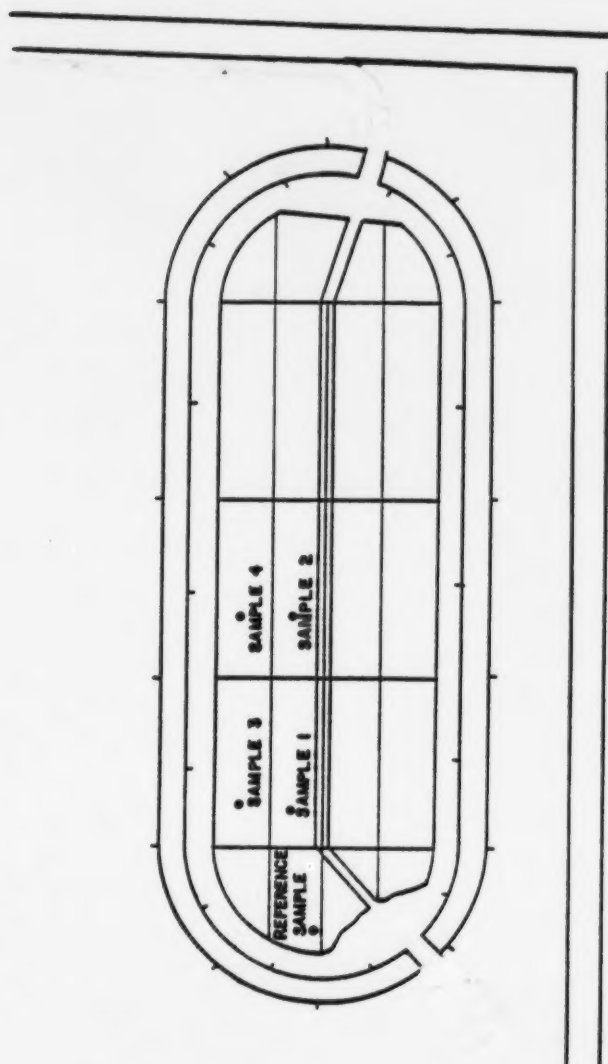


Figure B-3. Land treatment sample area for Site C.

Sampling Site: D. Sampling Date: January 7, 1981.

I. Topography

A. General Description: This site lies on a nearly level coastal terrace. A narrow land of moderately sloping and strongly sloping, loamy soils extends along the northern edge of the nearly level area. The surface has an almost uniform grade that slopes southeastward to the coast. The land treatment site is located on the top of a hill. The vegetation consists of native and sprigged coastal bermuda (Cynodon dactylon). The land treatment facility was ca 165 by 55 m (180 by 60 yds) and divided into 71 strips ca 2.1 m (7 ft) wide. There is a control strip at each end and alternating grass strips and treated strips.

B. Slope: The area consists of a 0 to 1% slope.

II. Soil

A. General Description: The soil of the site is Miguel fine sandy loam (0 to 1 percent slopes). This series consists of deep, loamy and sandy soils that contain a mottled claypan. Internal drainage is very slow in Miguel soils. Surface drainage is medium to rapid in gently or moderately sloping areas. Therefore, much water is lost in runoff, and the intake of water is very slow. The runoff could account for the loss of 2.54 cm (1 in) of soil from the typic Ap horizon which was 0-10 cm (0-4 in) instead of 0-13 cm (0-5 in) at the time of sampling.

B. Depth and Acidity (color, structure): The Miguel fine sandy loam occurs to a depth of 76 to 138 cm (30 to 55 in), and the pH ranges from 6.0 in the upper layer to 7.0 in the deeper layers. The parent material which contains hard and soft lumps of lime is pale brown and less clayey than the subsoil.

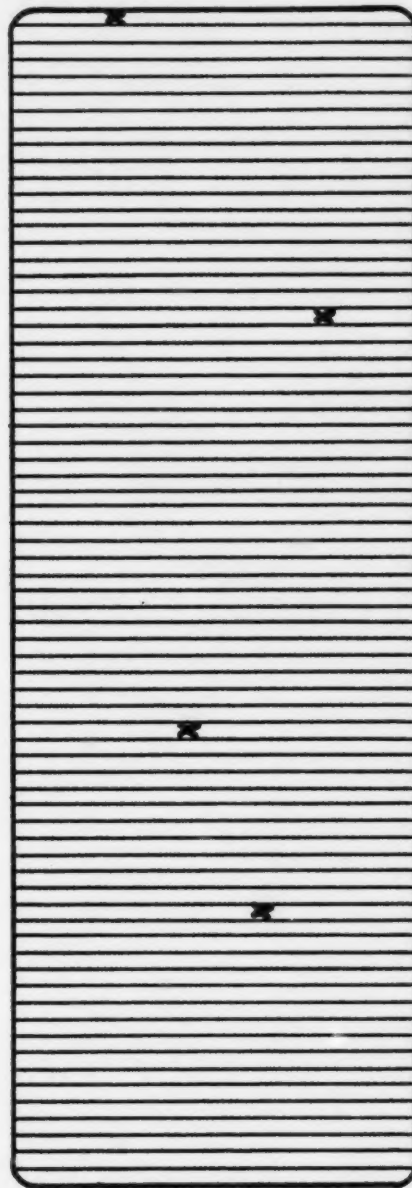
C. Profile (color, structure):

Ap - 0 to 10 cm (0 to 4 in), dark grayish brown (10 YR 4/2) fine sandy loam, very dark (10 YR 3/2) when moist; weak, granular structure; slightly hard when dry, very friable when moist, noncalcareous; pH 6.0; clear boundary.

- A₁ - 10 to 25 cm (4 to 10 in), dark-gray (10 YR 4/1) fine sandy loam, very dark gray (10 YR 3/1) when moist; weak granular structure; slightly hard when dry; friable when moist; noncalcareous, pH 6.0; abrupt boundary.
- B21t - 25 to 56 cm (10 to 22 in), dark grayish-brown (10 YR 4/2) sandy clay, very dark (10 YR 3/2) when moist; few fine, distinct mottles of red (2.5 YR 4/6) and many, medium faint mottles of yellowish brown (10 YR 5/6); moderate, medium, blocky structure; very hard when dry, firm when moist, plastic when wet; noncalcareous; pH 6.5; gradual boundary.
- B22t - 56 to 76 cm (22 to 30 in), gray (10 YR 5/1) sandy clay, dark gray (10 YR 4/1) when moist; common, medium faint mottles of pale brown (10 YR 6/3); weak, blocky structure; very hard when dry, firm when moist, plastic when wet; noncalcareous; pH 7.0; gradual boundary.
- Cca - 76 to 138 cm (30 to 55 in), very pale brown (10 YR 7/4) sandy clay loam, light yellowish brown (10 YR 6/4) when moist; strong, coarse blocky structure; very hard when dry, very firm when moist; many soft lumps and fragments of calcium carbonate; strongly calcareous; gradual boundary.

III. Climate

- A. Rainfall: The average annual rainfall is 69.8 cm (27.48 in) for the 40 years from 1940 to 1979.
- B. Pan Evaporation: Annual evaporation is 175.2 cm (68.98 in).
- C. Seasonal Temperature: The average temperature for the year 1940 to 1979 is 71.3°F.



X LAND TREATMENT SAMPLES

● CONTROL

Figure B-4. Land treatment sample area for Site D.

Sampling Site: E. Sampling Date: March 16-20, 1981

I. Topography

- A. General Description: The active site cores were sampled in a diked area surrounding a tank on the refinery site. The control core was sampled outside the diked area. The vegetation in the landfarm area consists of 60 percent St. Augustinegrass (Stenotaphrum secundatum) and 40 percent bermudagrass (Cynodon dactylon). There was some St. Augustinegrass (Stenotaphrum secundatum) grown on the site.
- B. Slope: The area typically has slopes which range from 0 to 3 percent; however, the land treatment site had a 5 percent slope in places.

II. Soil

- A. General Description: The soil is the Lake Charles-Urban Land complex. The Lake Charles series consists of deep clayey soils on upland prairies. The Lake Charles-Urban Land soil makes up 10 to 75 percent of the Lake Charles series. The Urban Land includes some remnants of Lake Charles soils that have been altered by cutting, filling, and grading. The soil history of the area sampled does include the removal of the topsoil from the area. The soil is somewhat poorly drained with the surface runoff typically classified as very slow or medium. Permeability and internal drainage are very slow. The soils in this series are clayey throughout the profile and are formed in alkaline marine clay. Undisturbed areas of these soils have gilgai microrelief, in which the microknolls are 15 to 30 cm (6 to 12 in) higher than microdepressions. The surface 30 cm (12 in) is not typical of topsoil, indicating the importation of materials. Below 30 cm (12 in), the soil shows typical profile characteristics.
- B. Depth and Acidity: The Lake Charles-Urban Land soil ranges from slightly acid through mildly alkaline, and this soil occurs to a depth of 188 cm (74 in).
- C. Profile
- Ap - 0 to 56 cm (0 to 22 in); black (10 YR 2/1) clay, very dark gray (10 YR 3/1) dry; moderate fine

blocky structure; very hard, very firm, very sticky and plastic; many fine roots; few roots; few fine iron-manganese concretions; shiny pressure faces; neutral; diffuse wavy boundary.

A12 - 55 to 91 cm (22 to 36 in); very dark gray (10 YR 3/1) clay, dark gray (10 YR 4/1) dry; moderate fine blocky and subangular blocky structure in upper 30 cm (12 in) and breaking to moderate fine and medium blocky in the lower part; the lower part contains common large wedge-shaped peds having long axes tilted 10 to 60 degrees from the horizontal and bordered by intersecting slickensides; extremely hard, very firm, very sticky and plastic; aggregates have shiny pressure faces; few fine iron-manganese and calcium carbonate concretions; mildly alkaline; diffuse wavy boundary.

AC1g - 91 to 132 cm (36 to 52 in); dark gray (10 YR 4/1) clay, gray (10 YR 5/1) dry; common fine and medium distinct mottles of olive (5Y 4/3) and few fine distinct mottles of yellowish brown (10 YR 5/4); common large wedge-shaped peds having long axes tilted 10 to 60 degrees from the horizontal and bordered by intersecting slickensides, peds break to moderate medium and coarse blocky structure; extremely hard, very firm, very sticky and plastic; few fine roots; aggregates have shiny pressure faces; few fine iron-manganese concretions; few calcium carbonate concretions as much as 1 centimeter (0.39 in) in diameter; mildly alkaline; diffuse wavy boundary.

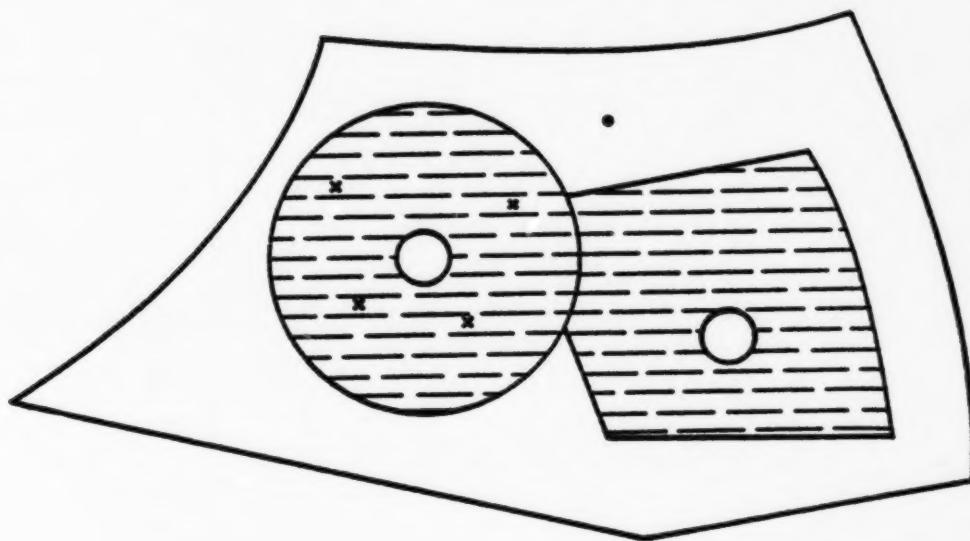
AC2g - 132 to 188 cm (52 to 74 in); gray (5Y 5/1) clay, gray (5Y 6/1) dry; common fine and medium distinct mottles of light olive brown (2.5Y 5/4) and few fine distinct mottles of yellowish brown (10 YR 5/6); weak fine angular blocky structure; extremely hard, very firm, very sticky and plastic; few fine iron-manganese concretions; few intersecting slickensides; few irregularly shaped pitted calcium carbonate concretions generally less than 3 cm (1.2 in) in size; mildly alkaline.

III. Climate

A. Rainfall: The average annual precipitation is 117 cm (46 in).

B. Pan Evaporation: The Thornthwaite P-E index is 183 cm (72 in).

C. Temperature: The mean annual temperature is 69°F.



x LAND TREATMENT SAMPLES

• CONTROL

Figure B-5. Land treatment sample area for Site E.